FARM SOIL AND ITS IMPROVEMENT

By

SIR JOHN RUSSELL, D.Sc., F.R.S.

DIRECTOR OF ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN

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FOREWORD.

This book is written for the farmer, and its object is to give him information about soils and manures which I believe to be sound, and which I hope will prove useful to him. It has been obtained from experiments on our own farm at Rothamsted and on other farms where we know the results are to be trusted, and it is presented briefly so that the busiest man may be able to read it.

The reader must not expect to find a clear cut set of prescriptions for general use; farming is of too complex a nature to allow of that. I have aimed at giving the broad principles on which a man must act, together with typical illustrations of how they apply on particular farms, but each individual farmer must always work out for himself the best application to his own case. New methods likely to be helpful should be tested by small trials to begin with: no one should be carried away by mere novelty, but at the same time it is unwise to leave too many of the advantages of a new method entirely to one's neighbours.

When any question arises as to the suitability of a new method or fertiliser to a particular farm the County Organiser should be consulted, and if the farmer does not know his address, or if there is no organiser, a note to the writer at Rothamsted will at once be attended to and such information as is possible will be given.

E. J. RUSSELL.

Rothamsted Experimental Station,
Harpenden.

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CHAPTER I.

SOIL FERTILITY: WHAT IT MEANS.

Soil fertility may be described as the capacity to produce good crops: a fertile soil is one that has this power and an infertile soil is one that lacks it. For our present purposes, however, it is necessary to go beyond this general description, and find out what causes the difference between fertile and infertile soils. Only when this is known is it possible to effect soil improvement.

Another way of describing fertile soils is to say that plants thrive on them, which means that they find on such soils all their requirements satisfied. We shall therefore have gone a long way with our problem if we find out what are the requirements of plants.

Botanists and physiologists have been busy for many years, and, although they would not claim to have discovered all about plants, they have shown that the main requirements are as follows:—

1. Air, not only for leaves, but for roots as well.
2. Water, sufficient, but not too much, and given at the right time.
3. Proper temperature.
4. Food, which must be of the right kind, given at the proper time and in the proper quantity.
5. Absence of injurious agents, of which a good many are known to exist.
6. Sufficient root room, which implies not only sufficient depth of soil, but freedom from excessive competition from other plants.

In a fertile soil all these requirements are satisfied; in an infertile soil some of them are not. It is important to remember that infertility arises even when one condition only is lacking. In such cases it may prove easy to put matters right; one has only to supply the lacking condition and the soil becomes productive. Sometimes, however, two or three of the necessary

conditions are lacking. Here improvement is more difficult, and, indeed, it may prove uneconomic. Nothing but complete rectification does any good, and money spent in putting only one defect right may be wasted.

This is well illustrated by the diagram given in Fig. 1, taken from Weir's "Productive Soils." Soil fertility may be likened to a tank; the capacity is determined not by the highest point on the side, but by the lowest. It would be little use piling up a side that is already high enough and neglecting the short stave that is allowing the water to run out. A small expenditure in the right direction does far more good than a heavy expenditure where it is not needed.

It is obvious that the proper way of dealing with an infertile soil is first to ascertain *why* it is infertile, and then *how* the faults can be remedied. And as the infertility might arise from any of the six causes set out above, it is further obvious that nothing but careful investigation on the spot, followed by such subsequent examination as may be necessary, will enable an expert to say why a soil is infertile. An analyst can say that this or that substance is present in a certain amount, but he cannot without direct inspection locate the cause or causes of infertility.

The six fertility factors set out above present some very interesting features.

Air Supply.

Most farmers realise that animals must have ample air supply, and would die at once if air were withheld. Plant roots are less sensitive, but they equally need air, partly for the sake of its oxygen, and partly (perhaps chiefly) in order to drive away the poisonous carbonic acid which they breathe out. In well-conducted laboratory experiments it is possible to remove the carbonic acid by other means, and then some plant

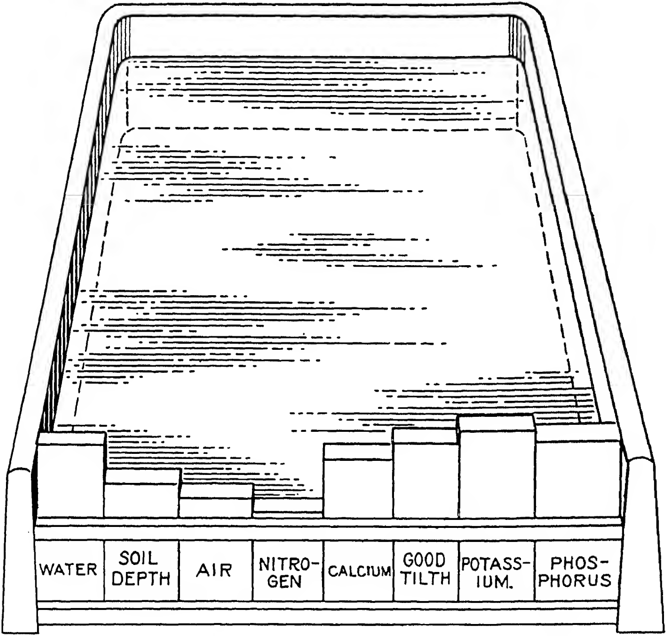


Fig. 1.—(After one in Weir's "Productive Soils.") Diagram to illustrate the fact that soil fertility depends on many factors, and it is no use spending money on improving one factor when another equally important one is neglected.

roots can get along without air; but in practice the only feasible thing is to allow sufficient access of air.

This does not mean that the soil is to lie loosely round the plant root. A reasonable amount of rolling does no harm to the air supply, because even after this has been done the soil still remains porous, and air has a wonderful capacity for finding its way in. But soils differ among themselves. Fig. 2 shows the marked effect produced on lupin roots. The plants were all sown at the same time and manured in the same way; they had equal supplies of water and equal conditions in all other respects, except soil. But here there were differences. Silver sand gives altogether the best root development; fine sand and silt come a long way behind. This fact meets with general recognition; sandy soils are preferred by nurserymen, and the light sands of Woking and the Thames Valley are the source of most of the shrubs sold in this country, the root systems being particularly good.

Air supply is not entirely a matter of soil, however, and much control is possible by cultivation.

Water Supply.

British agriculture has succeeded in adapting itself pretty extensively to variations in water supply, so that farming is carried on when the rainfall is as low as 19 inches a year—as in parts of North Kent—or rises as high as 100 inches a year, as in parts of the Lake District. The systems of husbandry and the methods of cropping have both been altered to suit the rainfall, and an interesting account could be written of the remarkable adaptations of local agricultural practice to climate.

If a line is drawn from Berwick-on-Tweed to the Isle of Wight it divides the country into two parts; in the eastern portion the farmer is mainly concerned with storing up such rainfall as he obtains, while in the

western part he is anxious to get rid of some of the excess. There are, of course, many exceptions, both in point of year and place; even in the dry parts of England some land has to be drained so as to get rid of excess of water, while many farmers in the western part are liable, at times, to suffer from drought.

If the corn grower could have rain just when he wanted and not otherwise, he would get along very well with about 20 inches of rain a year. But as the distribution is not always according to requirements, we find that 25 inches to 28 inches is more frequently the best quantity. A grass farmer wants more rain; he could quite comfortably do with 25 inches if he could arrange its distribution; but actually a margin is necessary, and 30 inches is in practice a safer amount, while 40 inches, 50 inches, or more, are not at all uncommon.

An inch of rain is, roughly, 100 tons per acre; it will be seen, therefore, that the requirements of the plant are very great. Compared with the food requirements it is enormous. No picture could show the difference, because no room would be big enough to hold it. If the actual food requirements of a 30 ton mangold crop are represented by a column an inch high, the water requirements would be represented by a column larger than Nelson's Column in Trafalgar Square.

Seeing how important water is to the growing plant, one cannot be surprised at the enormous stress laid by all expert growers on the need for cultivation. For it is by cultivation that the farmer regulates the water supply; he can arrange to get rid of an excess or to spread a meagre allowance over a long period. This art has been evolved by years of practice, and has reached a high pitch of perfection for the horse implements commonly used on farms. It is not clear, however, that the same rules will hold for tractor imple-

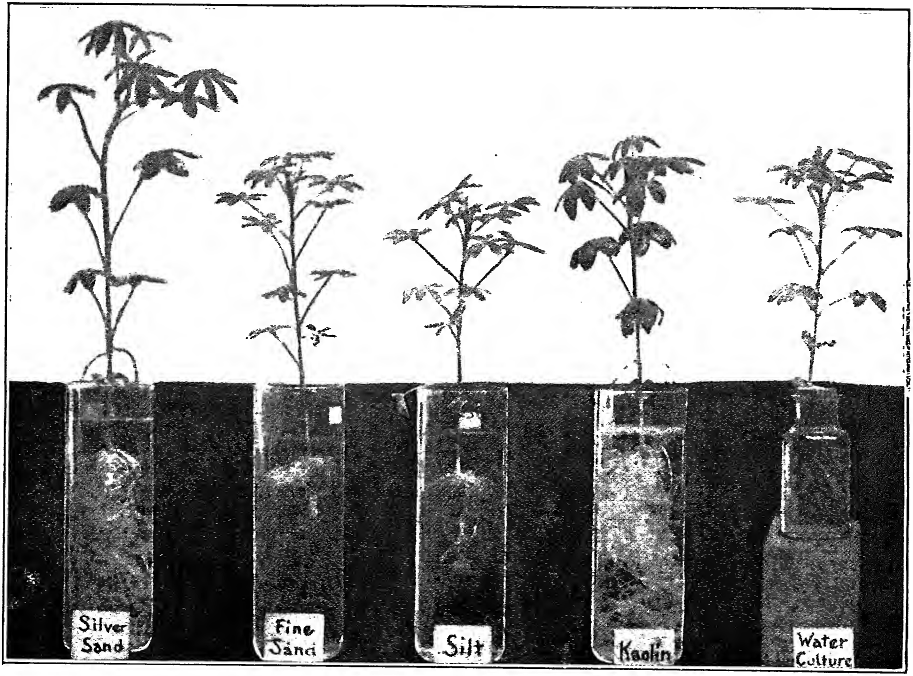


Fig. 2.—Showing the striking effect of soil aeration on root development. Lupins grown in silver sand or kaolin make better roots than those in water, silt, or fine sand, by reason of the larger air supply.

ments, and undoubtedly a good deal of investigation will be needed to settle these things. In the course of years agriculturists would no doubt discover the new rules for themselves, but few present-day farmers care to wait many years for information. Scientific investigation is much the more certain, and in the end, therefore, the quicker way: this is being carried out at Rothamsted.

TEMPERATURE.

Heat comes from the sun, and the amount of sunshine plays a great part in determining the farmers' methods. When the heat reaches the earth it is used up in a variety of ways, some of which help the farmer and some do not. It is difficult to increase the supply of heat, but there are ways of arranging the manner in which it is utilised and of deflecting it from useless to useful purposes. This, again, is done by cultivation.

FEEDING THE CROP.

In view of what is stated above it is not surprising that farmers are greatly impressed by the need of good cultivation, and that they call a man a good or bad farmer according as he cultivates his land well or ill. All this is perfectly sound: failure in cultivation means failure of crop, and no way is known by which it can be made good. But it is equally true that successful cultivation by itself is not sufficient to ensure profitable crops. On four of the Rothamsted fields there are plots which receive the best cultivation we can give them; they are sown with the best judgment we can exercise. But they are given no manure, and the results are very striking. Over an average of years the yields are:—

	Crops on highly cultivated but unmanured land: per acre	Crop necessary to pay expenses: per acre
Wheat	12½ bushels	32 bushels
Barley	12½ ,,	40 ,,
Mangolds	3½ tons	20 tons
Swedes	¾ ton	20 ,,

Fig. 3 shows what cultivation alone, and cultivation plus manuring, can do for swedes; and Fig. 4 shows the effects on wheat.

From all this it is evident that a farmer who relied on cultivation alone would not have a very successful time.

All experience shows that the plant needs food, and for many years chemists have been labouring diligently to discover just what sorts of food should be given. They have done their work so well that there are now more than 30 separate manures which can be made up in many ways to suit various crops, soils, and conditions. As an example, in the case of Potatoes no less than 6000 good receipts can be made, for each of which could be claimed some special advantage either in price or effectiveness in conditions to be found in this country. When it is remembered that most farmers grow ten or twelve different crops, each of which requires some peculiarity in manurial treatment or mixture, it becomes evident that the subject of manuring is by no means simple, and would-be experts who undertake to tell "all about manuring" have undertaken a very tall order. Certainly the present writer has no intention of attempting to describe all possible manurial mixtures.

FOUR GENERAL RULES.

There are, however, certain general rules which will be found useful to farmers. They are as follows:—

1. Farmyard manure, lime and limestone benefit the soil as well as the plant; artificial manures benefit the plant, but not usually the soil.

2. Proper combinations of artificial manures increase the growth of plants, and up to a certain point the more the manuring the greater the profit to the farmer. But the feeding cannot be carried out indefinitely, and additional food beyond the right amount brings less

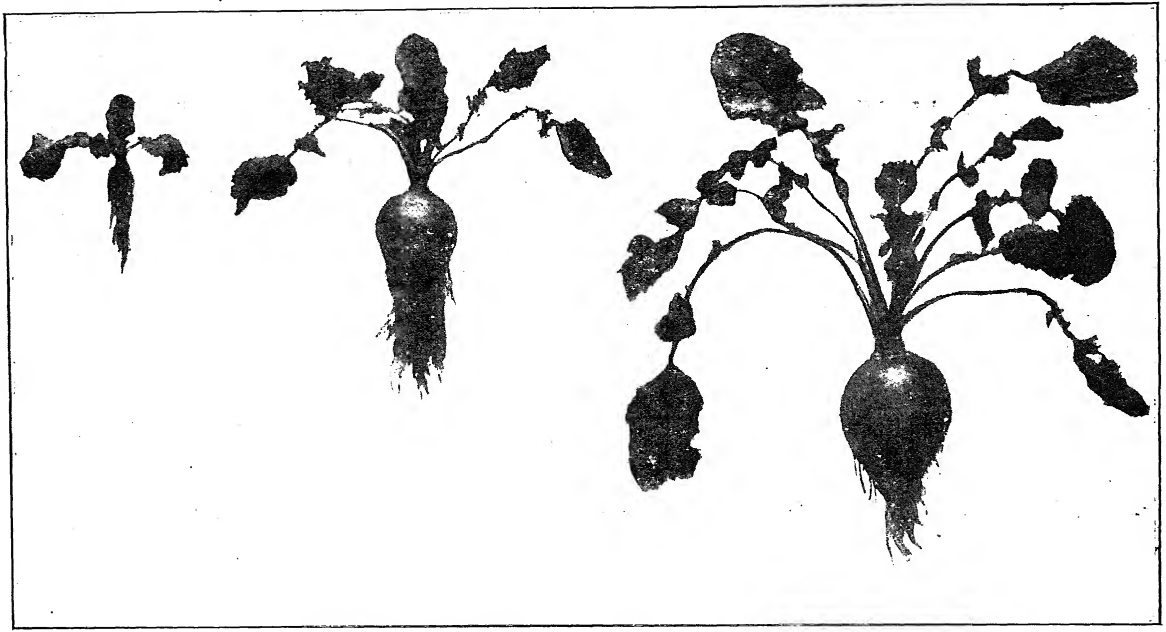


Fig. 3.—Swedes grown on the Rothamsted plots.

A—Good cultivation, but no manure. B—Same cultivation, incomplete manure. C—Same cultivation, complete manure.

profit, and may do actual harm. In short, farmers must *manure with brains.*

3. Like the animal, the plant must have its food at the proper time. No sensible farmer would dream of keeping his animals without food till they began to drop down from starvation. If he adopted this course, and then gave them a good meal, he could hardly be surprised if they became very ill. But most of us have seen corn crops that have been left to go yellow or to suffer a severe check before manure was put on, the plea being that the crop should have a top-dressing if necessary, but not otherwise. The proper course is to anticipate the needs of the plant and supply them by a suitable spring application if last year's cropping and manuring have not left a sufficient reserve in the soil, or if the winter rain has been so severe as to wash out what ought otherwise to have been enough.

4. Plant food not only increases the crop, but alters it in various ways, either for better or for worse.

Thus:

(*a*) Nitrogen compounds stimulate growth and allow the plant to grow away from insect pests, but in large quantities they give a dark-green colour, a thin cell wall, a cell sap that seems to suit some of the fungi causing disease; at any rate, they increase the liability to disease.

(*b*) Potassium compounds improve the grain, give extra vigour to the plant, enabling it to overcome the ill-effects of bad seasons, to throw off the effects of certain disease organisms, and generally to help it over difficult periods.

(*c*) Phosphates alter the composition of the plant, greatly improving its feeding value and its quality; they encourage root development, early growth and early maturity; they are thus of great value in wet, cold conditions; in clay soils, etc. But

they may hasten ripening too much, and on sandy soils they have sometimes depressed the yield of grain.

It is necessary to emphasise these effects on the plant because they explain a fact which is quite familiar to observant farmers all over the country. It is well known that a manure which proves economical and successful in one part of the country may prove much less useful in another district. To some extent the difference lies in the soil, but a very real factor is the climate. From the above it is explicable why potassic fertilisers are so effective in glasshouse culture: they help the plant to maintain the high level of productiveness necessary for so costly a method of growth, and also to resist the attacks of some of the organisms that play havoc under glass once they become established. Further, we can understand why it is that farmers in East Kent, under a rainfall of 20 to 24 inches, obtain satisfactory returns from potassic fertilisers, while in West Sussex, under a rainfall of 30 to 36 inches, they do not, but prefer instead phosphates. The phenomenal success of phosphates on cold clay soils arises in part from the great effect on root development: the natural conditions are not very favourable, and this additional stimulus proves very effective.

These properties will be discussed more in detail when we come to the question of individual fertilisers, but it is necessary to state them at the outset so as to emphasise the fact that manures are used for two purposes: (1) to increase the crop; this is familiar to every farmer. (2) To change the plant somewhat and make it rather better suited to the farmers' needs, as when the feeding quality is improved; or rather better adapted to the local conditions, as when root growth is stimulated on a heavy soil not in itself very encouraging to root production.

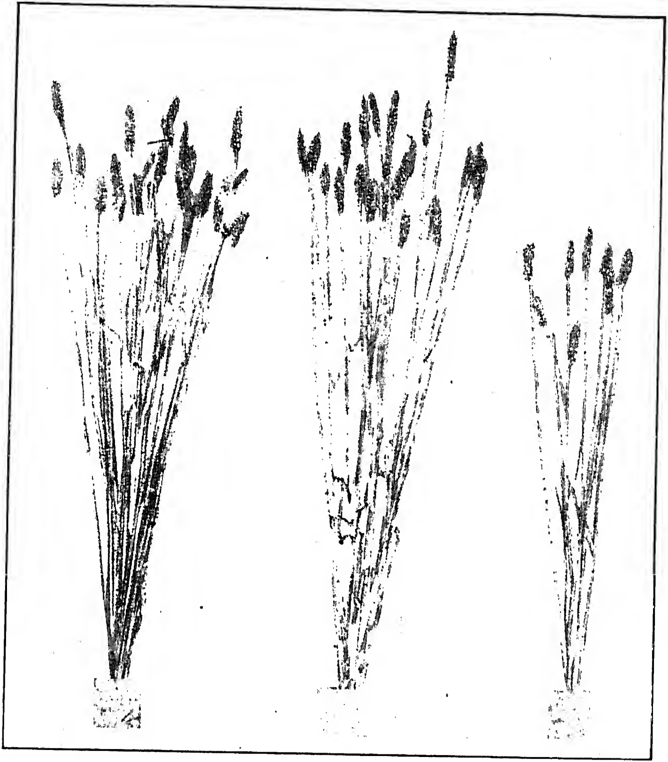


Fig. 4.—Wheat grown on the Rothamsted plots. All plots receive the same cultivation, but different manures.

Absence of Injurious Factors.

For many years chemists have discussed the possibility of the presence of harmful or poisonous substances in the soil, and the general result is that while these do not usually occur, they may be found in special conditions, especially in wet or sour soils. These will be discussed in a later chapter.

Root Room or Absence of Competition.

This is one of the most important factors in fertility and one which is often overlooked. Plants cannot survive without their roots, and unless ample room is allowed for development the roots cannot possibly do well. Not only must the soil be sufficiently dry to permit the roots to go downwards, but there must be sufficient space between the rows to allow them to grow sideways as well. The depth may be limited by a layer of rock, of gravel, of impenetrable clay, by a pan, a water table, or through various other causes. Lateral or sideways development may be impeded by too close sowing, but more usually by weeds. The chief reason for keeping down weeds (many of which in themselves are unobjectionable) is that they take up root space that the crop ought to have. And so it happens that good cultivation not only increases the water supply, air supply, and temperature for the plant root, as already stated, but it increases also the root room by keeping down competitors.

CHAPTER II.

THE SOIL AS NATURE LEFT IT.

It is commonly supposed that a virgin soil must be a rich soil and that the state in which Nature leaves it is necessarily a good one for crops. But many settlers and real estate agents in new countries have a very different tale to tell, and there are numberless tragic stories of men who have lost everything they had through relying on the fertility of virgin soil. Most eloquent of all are the figures of yields of new countries as compared with old ones where there is no virgin soil. They are as follows:—

YIELDS OF WHEAT, BUSHELS PER ACRE.

New Countries.		Old Countries.	
Canada	21	Belgium	38
Australia	11¾	Denmark	36
United States	14	Great Britain	32
Argentine	10½	Germany	33
		France	20

The fact is that high yields are largely the result of generous expenditure on seeds, fertilisers, and labour, and are only in part due to natural fertility.

But while the value of virgin soil must not be overrated, we must not make the opposite error of minimising it. The value of a deep loam as compared with a clay or a shallow chalk soil is well known. Now this is entirely a natural difference: there is no artifice known by which a clay can be converted into a loam, although constant unremitting effort may do something to reduce the great difference between them.

The value of natural fertility shows itself in three directions:—

1. In the physical constitution of the soil; whether it is clay, sand, loam, chalk, etc.

2. In the amount of calcium carbonate (variously spoken of as lime, limestone, chalk, etc.).

3. In the capacity for accumulating organic matter.

All are important, the first most of all, because it cannot

Fig. 5.—Influence of the subsoil. This land cannot be cultivated because the soil is too thin for a gravel subsoil. "No Man's Land," Wheathamstead.

be altered; the second and third only little less so, because the alteration, though feasible, costs money, sometimes more than can profitably be spent.

The Formation of Soil.

The physical constitution of the soil was settled long ago as the result of great geological changes which are still proceeding, but which operate so slowly that their effects cannot be measured in the lifetime of the farmer. As an example, on the eastern side of Hertfordshire there are some gravel soils which are so stony that they afford a very poor living to the cultivator, whilst others are so hopeless that they are simply left as wastes and commons: one near Harpenden is shown in Fig. 5; it receives the significant name of "No Man's Land," and to this day cannot be cultivated. Adjoining some of these are quite nice strips of loam running sometimes almost to sand, and at other times on the heavier side. But how many of the farmers who struggle on the gravel soils, envying their neighbours on the loams, realise how it comes about that their soils are so stony and the others so good? The tale is a fascinating one, but space forbids it to be told in full.

Long ago—geologists will not commit themselves as to time, but estimates have been put forward varying from 500,000 years to 1,000,000 years—the whole of England north of the Thames was covered with a huge ice cap. At its fringe, as it melted, the glacier streams poured out, as can be seen in Switzerland at the present day, and the rushing torrent swept away the soil, leaving only stones and gravel. But where for any reason a large pool or lake was formed there the finer soil particles were deposited, as happens to-day in any lake that is being silted up. The ice has long since gone, but the stones and the fine soil deposits still remain to show how the water flowed, and till the end of our time farmers on the stony soil will continue to suffer

as they have suffered since the beginning, because the streams in those remote ages happened to flow quickly over the place where they now farm, while on their more fortunate neighbours' land the flow was slower, so that the fine particles could be deposited. It is small consolation to reflect that had some accidental boulder deflected the stream but a few yards at its source the whole agricultural history of a dozen parishes might have been different for the last 2,000 years.

ORIGIN OF SOIL CHARACTERISTICS.

But this sorting out and transportation does not end the matter. The soil particles themselves have a much older history which goes back to the time when the earth first cooled sufficiently to have a solid crust. Since then the rocks have broken down to give soil particles of various sizes; they have sometimes been under water and sometimes on dry land; sometimes under subtropical conditions, sometimes in an Arctic climate. Always some changes went on, but there were times when they were so much more marked than usual that the particles became profoundly altered, and nothing that has since happened has obliterated the changes then produced. Take, for instance, the admirable red soil, known to the geologist as Triassic, occurring in a strip of country running northwards from Devon (near Exeter) west of the Severn, through Hereford, Worcester, and Warwick, then forking, part through Stafford to Cheshire, and part though Leicester to Notts, west of the Trent; compare these with the grey heavy soils of the Lias formation just to the east. There is an enormous agricultural difference, but it goes back to days vastly more remote than those of the Ice Age; when Triassic soils were being formed under dry, sometimes desert conditions, with much wind-drifted material, whereas Lias was produced under water in a wholly different way. Changes have gone

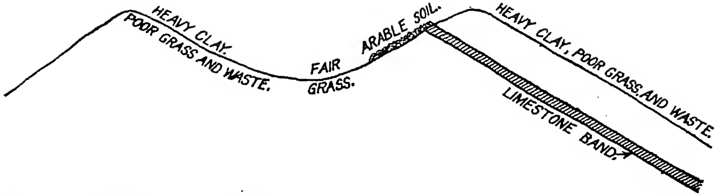


Fig. 6.—Section across Lias clay country, near Shipston, Oxfordshire. Too heavy to cultivate, except where modified by the outcrop of limestone.

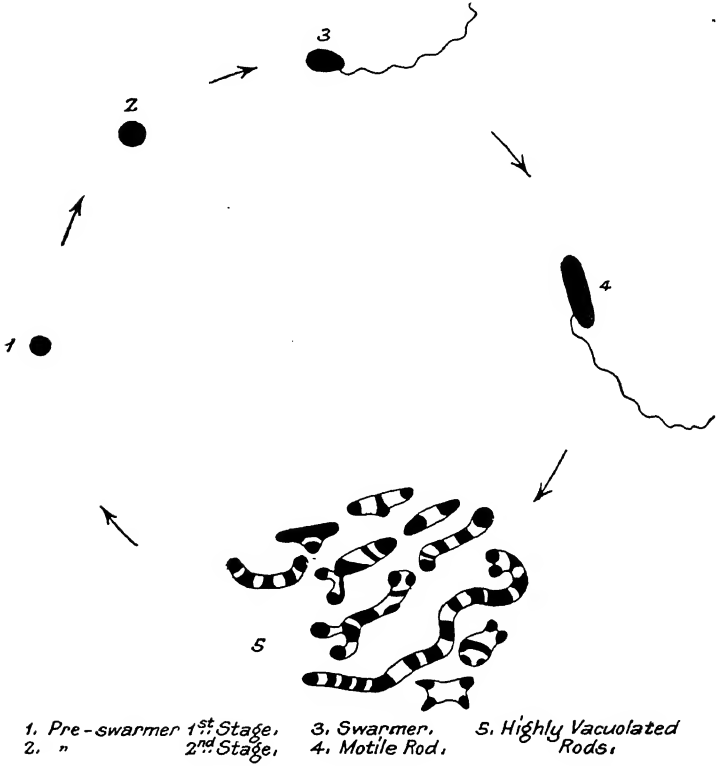


Fig. 7.—Some of the changes through which the clover organism passes during its complete life. Very highly magnified. If No. 1. were magnified to the size of a football, a man on the same scale could have his head in England, his body could stretch across France, and his feet could lie in the Mediterranean Sea.

on ever since, but they have never yet reduced the Triassic to the state of the Lias soils. Many similar cases can be quoted; these differences all go back to very remote times. The soil as we see it to-day is the result of actions that took place hundreds of thousands or even millions of years ago, modified by actions that have been going on ever since. The key to the present state of the soil lies in its past.

The history of our soils is continuous in the same kind of way as is our own history; there are occasional revolutions and upheavals, but in the main the changes are gradual, so that it would be difficult to say exactly when any particular change set in. It is, however, more easy to mark off ages or epochs. So in dealing with soils it is easy to see that during certain epochs the conditions were such that all the finest particles were washed or blown right away, leaving a sand; or that the conditions allowed a considerable deposition of fine particles, giving rise to a clay; but there is not always a sharp change from sand to clay, and the intermediate zones or strips show where the conditions were changing and the new order was becoming more and more in evidence.

Occurrence of Limestone or Chalk.

The second great direction in which Nature has operated has been in regard to the distribution of calcium carbonate. It is an old saying that "a lime country is a rch country," and it embodies the fundamental truth that the cultivator's task is greatly lightened when the soil contains a sufficient amount of this substance. It sometimes occurs in masses as limestone or chalk, but in many cases it is mixed in small quantities with the soil. Frequently the soil overlying chalk or limestone contains little or no calcium carbonate in spite of the immense quantities lying below. This fact has often astonished farmers who, seeing the

closeness of the chalk to the surface, have thought it inconceivable that the soil could possibly lack this particular substance; yet so it often happens. Particularly interesting cases occur on the Lias clay already referred to where a band of limestone outcrops, giving a strip of workable arable land along it and so far below it as its downward wash or drift extends, but not above it. This is shown in Fig. 6, illustrating a section of the country between Shipston and Stratford-on-Avon, where the land is workable and possesses distinct agricultural value so far as the effect of the calcium carbonate extends; but outside this it carries very poor grass, and is, in places, waste land.

Of course this inequality can be put right by dressings of lime, limestone or chalk, but these cost money, and, moreover, the dressings are not permanent, but wash out at the rate of about 5 to 10 cwt. per annum.

Accumulation of Organic Matter.

The third great effect of natural conditions is to determine the extent and the method by which organic matter accumulates in the soil. When plants grow in a state of nature they are not commonly removed from the soil, but remain till they die and then fall on its surface. Several things may happen to them: they may simply stay there and gradually give rise to peat; they may become intimately mingled with the soil by various processes, forming black earths, often quite rich; or they may not accumulate at all, but just disappear as in the majority of fertile clays, loams and sands. The effects on fertility are so profound that thy must be left for discussion in a further chapter.

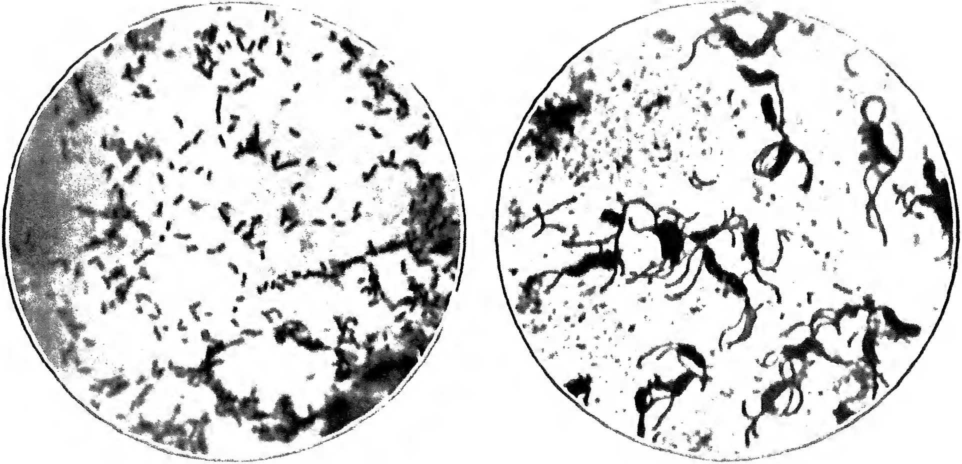


Fig. 8. Soil bacteria. Each little rod is a separate creature, very highly magnified

CHAPTER III.

THE SOIL AS THE ABODE OF A GREAT POPULATION.

Crops are grown almost entirely to supply food for man or beast; there are a few exceptions, such as tobacco, fibre plants, cotton, etc., but these do not affect the ordinary farmer. Food is to the animal or man precisely what fuel is to an engine; the resemblance is so close that physiologists use the same terms as engineers and describe food units in terms of their energy supply, or "calories": this is a very convenient mode of reckoning, since it is known that the growth of the crop involves the fixation of the sun's energy by the plant. The following are typical instances of the energy values of crops:—

	Average Yield per acre, lb.		Energy value, thousand million calories.			Equal to the following number of tons of coal.
	Grain.	Straw.	Grain.	Straw.	Total.	
Wheat	1,920	2,690	4.4	5.4	9.8	1 ton 2 cwt.
Oats	1,540	2,350	3.5	4.7	8.2	18 cwt.
Permanent Hay	—	2,500	—	—	5.0	11 cwt.
	Tubers.	Leaves.	Tubers.	Leaves.		
Potatoes	14,100	10,000*	5.2	2.0*	7.2	16 cwt.

*Estimated.

If these crops are taken away the energy, of course, goes with them, but when vegetation is left undisturbed, or when, as in green manuring, it is ploughed into the ground, the energy is added to the soil. In some cases, as in peat soils, the energy supply accumulates and becomes so great that the peat can actually be used for fuel; in others, as in old pasture, it is less, but still sufficient to allow the soil to be burnt in heaps without difficulty by a skilled man. In most cases the soil is not burnt and the energy does not accumulate indefinitely; something happens to it, but what?

Nature Prodigal of Life.

It is established as definitely as is possible for any physical fact that energy is not lost; it may remain stored up, or it may be used for giving heat or doing work, but whether the plants are fed to an animal, burnt in a bonfire, or rot in the soil, they will have given out the same amount of energy by the time they are brought to the same final state. Nature never seems to lose a chance of establishing life, and the great store of energy in the soil is used by a vast population of living organisms of the most varied kinds. No life is possible without energy supplies, and the plant residues in the soil maintain a large population.

Beginning with the big things, the earth-worms play an important part by drawing leaves, stems, etc., into the soil and causing quite an effective mixture. They eat up some of this material, dissipating part of its substance as carbonic acid gas and water, but fortunately effecting no loss of nitrogen, potash, and phosphates. Then there are centipedes and millipedes that are readily seen, and, in addition, a vast array of insects and other animals visible to the naked eye that most people pass by because they are not very noticeable. Mr. Morris, at Rothamsted, has counted their number in the soil of the Broadbalk wheat field and worked out the results per acre; they are :—

		Total Numbers per Acre.	
		No Manure.	Farmyard Manure.
Insects		2,475,000	7,727,000
Acari (such as mites, etc.)		215,000	532,000
Earthworms		458,000	1,010,000
Myriapods (such as millipedes, centipedes, etc.)		879,000	1,781,000
Dominant Insects,	1st	Collembola (693,000)	Ants. (2,946,000)
	2nd	Ants (690 000)	Collembola (2,391,000)
	3rd	Wireworms (165,000)	Chironomid Larvæ (510,000

THE INVISIBLE LIFE IN THE SOIL.

But when we pass from the visible to the microscopic life the number and variety of the forms become very great. In a single teaspoonful of good arable soil there are more living organisms than there are men, women, and children in the United Kingdom. Some of these organisms are harmful to the plant and may cause diseases, such as finger-and-toe in turnips or cabbage, "tulip root" in oats, scab and wart disease in potatoes, "cockles" in corn, clover sickness, etc. Many have no direct effect on the plant, but a considerable indirect effect; for they completely break down the plant residues ploughed into the soil, changing them into something wholly different. And the remarkable feature of the whole change is that the original plant residues are of no use to the growing plant, but rather the reverse, because they would open up the soil too much and make it too liable to dry out; while the new substances formed by many of the soil organisms are just the things the plant needs.

It would be a mistake, however, to look upon the soil organisms as existing in the soil for the benefit of the farmer: they are there living their own lives just as independent of the farmer's wishes as he is of theirs; but if he gives them the right conditions they will do a prodigious amount of work for him. Like plants, they must have air, moisture, suitable temperature, and food; and also, like most cultivated plants, they do not care for acidity, so that it is necessary to add sufficient lime, limestone, or chalk. Their requirements are so similar to those of plants that in some directions they are actual competitors with plants. When straw is ploughed into the ground the organisms proceed to decompose it, but not finding enough nitrogen there for their own needs, they promptly take some of the soil nitrates which the plant would otherwise have had, and so for a time reduce the amount of plant food.

This is one of the reasons why "long" manure is inferior to well-rotted manure in spring, and it justifies the farmer's preference for a certain degree of decomposition in farmyard manure before it is applied to the land.

NITROGEN FIXERS: THE FARMER'S ALLIES.

Two remarkable cases of action of micro-organisms deserve mention. It is well known that nitrogenous manures are now made from the air by special processes involving large, well-organised factories, electrical power, highly-elaborate appliances, skilled engineers and thoroughly competent chemists. It is not so well known that soil bacteria do all this and much more which cannot yet be repeated in factories, and they do it, moreover, without any of the paraphernalia of the factory. Some of these organisms (shown in Fig. 7) live in nodules on the roots of clover, peas, vetches, and other leguminous plants; they are greatly favoured by lime, by phosphates, and apparently by farmyard manure. To secure their co-operation the method is to grow leguminous crops as frequently as is feasible, and thus to obtain at one stroke a good fodder crop and a good manure. Other nitrogen-fixing organisms live in the soil quite apart from any crop: they help to bring about the great accumulation of nitrogen that takes place when land is left in sod—the cheapest and one of the best ways of increasing fertility.

DESTRUCTIVE ORGANISMS.

But besides the organisms that fix nitrogen there are others that liberate it from nitrates, thus undoing all the good work the nitrogen-fixers have done. This happens particularly in water-logged conditions, and it comes about because the organisms need air—as we do—but unlike ourselves they can extract their necessary oxygen from nitrates if the air supply is cut off, whilst we should perish. Thus the injury they do

the farmer is not essential to their activity, but results solely from an insufficient air supply, and is therefore capable of being remedied.

The similarity in requirements of growing crops and of the useful soil organisms greatly simplifies soil fertility problems, and it emphasises all that has been said about the need for adequate supplies of air and water and temperature in the soil. The methods of securing these will be discussed in the next chapter.

CHAPTER IV.

CULTIVATION.

DRAINS AND THE TRACTOR.

In previous chapters we have shown the serious need at every turn for air, water, and proper temperature supply in the soil, and it has been pointed out that these can be secured by cultivation and drainage. We must now go into some details to show how and why these operations are performed. First in importance comes drainage, for without this—where it does not occur naturally—no other process will benefit. It does not always follow that a wet soil needs the drainage; in the sticky clays of Herts, Bucks, Beds, North Surrey, and North Kent (but not mid-Kent) a dressing of chalk will often make the soil sufficiently porous to allow the water to get away. However it is done, *a way out must be found for the soil water,* otherwise all the undesirable effects already described will be produced. *Lack of drainage is an important cause of the farmers' lack of profit.*

We begin with the simplest case where a heavy soil lies on a porous foundation, as the stony clays of the counties above mentioned, which lie on the chalk. A dressing of 20 loads per acre of fine chalk or 50 loads per acre of lump chalk makes the clay sufficiently porous to allow the water to soak into the chalk, and it then gets away very easily. Usually the chalk comes up in places to within 3 feet to 6 feet of the surface, forming peaks which tap the water and provide a natural way out. A water furrow is often necessary, but in some places a dell, such as is left when chalk has been lifted from the field, is desirable for very wet parts.

DRAINAGE SYSTEM.

If, however, the clay lies on a still heavier clay, as happens in most parts of England, this simple pro-

Horse Plough, 1919.

Tractor Plough, 1921.

Fig. 9.—The Old and the New Methods of Cultivation.

cedure is not sufficient, and a drainage system is necessary. The easiest to install is the open drain, formed by casting out a furrow, and this answers satisfactorily on light peat soils under very heavy rainfall. In these cases there would be no special difficulty if the rainfall were round about 30 inches, but trouble arises when it amounts to 70 inches, 80 inches, or 100 inches in the year.

More usually the trouble is due not so much to high rainfall as to heavy soil, and the open drain does not met the case. The cheapest procedure is to *mole drain,* and farmers who are not familiar with this process should look into it, as it has repeatedly proved both effective and economical in dealing with wet land. The principle is well known: a steel cylinder with a pointed nose that makes it look like a shell is attached by a very rigid bar to a frame, which is then hauled over the land by steam tackle, the cylinder being dragged through the earth at a distance of 1 foot to 2 feet below the surface, thus leaving a tunnel like that formed by a mole. It is, of course, necessary to put in pipes where the drains run out into the streams, but the amount can be reduced by intelligent arrangement of the mains; it is an economy in the long run to brick the final opening. Mole draining answers best on grass land where there is sufficient slope (very little is enough), but it breaks down on stony soils.

Pipe Drainage.

In spite of its cost, some pipe drainage is always being carried out; it lasts longer than mole drainage and is more convenient where only a small amount of work has to be done. But it is costly, and therefore the most economical procedure is to work out the scheme very carefully beforehand, to record it all upon a plan, and then to *preserve the plan where it can be found in twenty years' time.* For even the best-laid

pipes will get clogged in time, and if the drains can be easily located they can be cleaned. But how often have I been over farms and been told: "We know the land has been drained and we know the drains are blocked somewhere; but we can find no plan. We do not know where the pipes are, and so we can't unstop them. What are we to do?"

No one nowadays would repeat the mistakes of the "Government drains" of the 'forties of the last century and lay the drains too deeply. Modern practice is in favour of shallow drains, at about $2\frac{1}{2}$ feet to $3\frac{1}{2}$ feet depth, and distant about 15 feet to 30 feet apart, the pipes being commonly 3 inches in diameter. The work of excavation can be lightened by the use of a mechanical excavator, of which several types have been made. The depth depends very largely on the fault to be remedied; if the water is rising up from below by seepage from higher ground, the drain must be rather deep so as to cut it off early; if, however, the excess of water is due simply to rain, the drains should only be laid at a shallow depth.

The mention of seepage water from higher ground emphasises the need for a carefully thought-out plan. Elkington made fame and fortune for himself by the simple device of cutting off the sources of excess water on his own and many other people's land, and by a simple system tapping the underground water at its source, thus saving the necessity for an elaborate drainage scheme. In working out a plan the first questions to ask are, "Where does the water come from?" and "Where ought it to go to?" Having found the answer to these, the plan should be drawn up accordingly.

Great stress has been laid on drainage because it is necessary in many parts of the country, and it has been neglected of late years. Unfortunately it does not entirely depend on the individual farmer's efforts; a

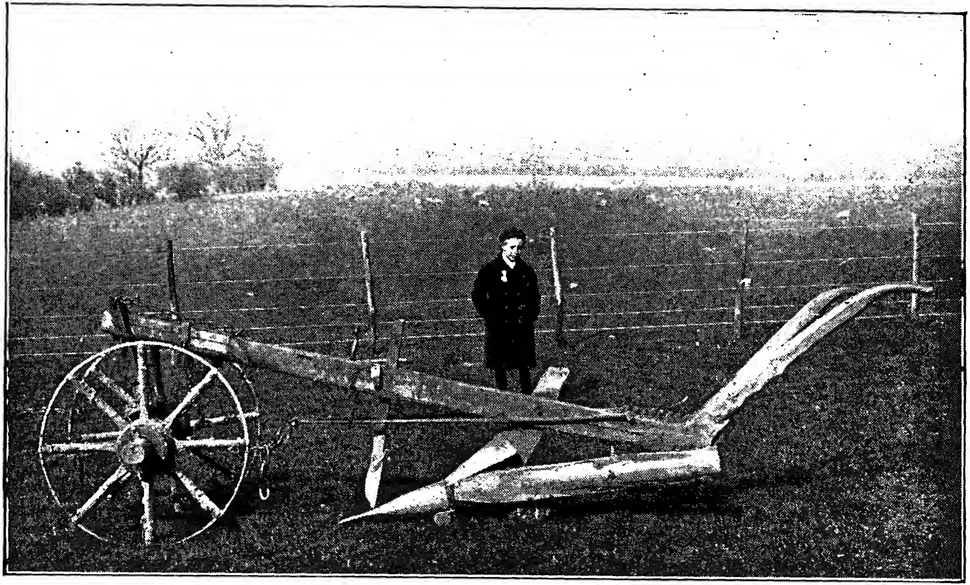


Fig. 10.—The Kent Plough, a good implement, which even now is not easily beaten.

man may drain his own land and keep his own watercourse clear, but unless his neighbours above and below him do the same he will not reap the benefit to which he is entitled. Only a Drainage Board having extensive powers of cleaning and straightening ditches and small streams could ensure the full return from farm drainage. The best results can be secured only by co-operative efforts over all of the river system that counts.

Cultivation Proper: The Tractor.

Ten years ago it would have been comparatively easy to say what was known about cultivation; to-day the problem is much more difficult, because the tractor has come in and completely upset all our ideas of what is possible in a given time. A single man can now roll twenty acres per day; even on a heavy soil he can cultivate eight acres, cross-plough four acres, and break up two acres of a hard-baked stubble—all this within the regulation hours and without the payment of a penny of overtime money. But if matters are pushed and the man is willing, he can go on at the same pace from daylight to dark without having to stop to rest the tractor.

This speed of working allows the farmer to prepare his land for sowing at whatever time he finds best. Seed sown at the proper season has the best chance of development, while seed sown out of season has not. For each soil and locality there is often useful local experience; in our case at Rothamsted, winter corn must be sown early; oats, if possible, before the middle of October; and wheat before the middle of November. With horse implements much of the land was often not ready in time; with the tractor it has all been ready. The following figures show the result of early and of late sowing, the variety, seed, and manuring being otherwise the same:—

Wheat sown in time (November 24th, 1915)	...	$26\frac{3}{4}$ bushels
Wheat sown late (February 17th, 1916) ...	...	$19\frac{1}{4}$,,

The following are some of the estimates that have been drawn up for the cost of ploughing an acre of land :—

Year.	By Horses.	By Tractor.	Authority.
	£ s. d.	£ s. d.	
1919	1 12 8	1 1 6	Rothamsted Report, 1918-20.
1920	2 0 9	1 5 10	" " "
1920	2 9 4	1 0 4	Mr. B. Howkins, Bedford ("Agricultural Gazette," April 29th, 1921).
1920	Light land, 1 2 6 Medium land, 1 12 6 Very strong land, 2 2 6		Mr. John Ewens, Lincoln (*Ibid*).
1921	8 9		Mr. James Falconer, Farmer's Club J.L., 1922. Page 93.
1921	1 2 11	1 0 1	Mr. C. E. B. Fisher, Farmer's Club J.L., 1922. Page 103—Light land.
1921	1 11 8	0 18 2	Rothamsted Report, 1921-22—Heavy land.
1922	1 1 0	0 15 0	
	Time required: 10½ hours.	3 hours.	

The tractor, however, needs proper attention and a certain amount of knowledge of its construction by the farmer and the driver. Without this it is often out of use for some very trifling reason that should never have arisen. And, moreover, on some types of soil (e.g., blowing sands) it is not very suitable.

Autumn Cleaning of Stubbles.

Weeds are liable to accumulate in corn crops, and unless kept down they may cause trouble in the rotation. An effective method of checking them, when it can be practised, is to cultivate the stubbles.

It is not possible to lay down a hard and fast rule, and say whether the plough, the scarifier, or the broadshare is the best implement; much depends on circumstances. There is, however, a great deal to recommend the broadshare, especially if it is used immediately after or, if possible, during harvest, and before the surface of the soil has become too dry; for it will then cut off living weeds from their roots, and will sufficiently pulverise the surface soil to allow of the germination of the weed seeds, so that the seedlings can be killed by later cultivation.

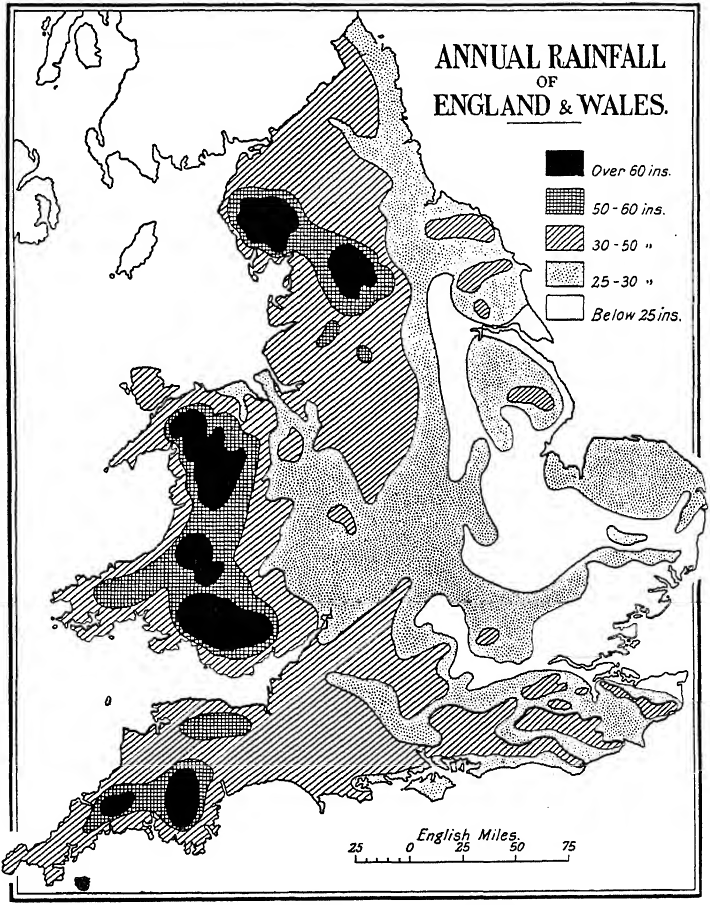


Fig. 11.—Distribution of Rainfall in England and Wales.

Where winter corn is being grown it is sometimes difficult to decide whether to give an additional cultivation or to sow earlier; usually, however, the cultivation is best as nothing ever quite makes up for lack of autumn work.

In old days winter wheat was often sown on a stale furrow, but modern ploughs are so effective that sowing on a fresh furrow usually proves satisfactory, the land being ploughed one day and sown the next.

Good results have recently been obtained by sowing wheat, spring oats, and barley quite near to the surface instead of at the depth now usual; the plan should be tried on a small scale in the first instance.

Spring Cultivation.

The cultivation for spring crops consists in the preparation of a seed bed, and the best conditions for this on heavy soils are that the land should have been ploughed in autumn, left rough during winter, and then worked down in spring; the best time for harrowing down the lumps being when they are freshly wetted by rain after having been tolerably dry. It is a curious fact that a heavy soil containing a certain proportion of water may exist in two states, according as it is becoming wet after being long dry, or become dry after being long wet. If it is passing from wet to dry, attempts to reduce it to a fine state may do harm; but if it is passing from dry to wet a fine tilth is much more easy to secure. On such soils the farmer must hope to escape a wet spring following on a wet winter, and if the seasons are usually of this character he will do best to arrange a rotation in which the land is for some years in temporary grass.

For roots a fine tilth is essential, as every farmer knows, but there is a more difficult problem: should they be grown on ridges or on the flat? In the north

ridges are almost universal, and, as is well known, in the north the crops are very good. In the south the roots are often grown on the flat, and the yields are considerably smaller. But it does not follow that the ridging accounts for the difference; as a matter of fact, the balance of evidence is that in the southern and eastern counties swedes, turnips and mangolds do better on the flat than on the ridges.

Hoeing, Rolling and Fallowing.

Hoeing is very necessary. Root crops are often taken on land that needs cleaning, and no crop can stand the competition of weeds. Further, root crops suffer more than any other from drought, and the hoeing affords the only way in which a farmer can mitigate the ill-effect of dry weather once the crop is in the ground. In really dry climates the disc harrow is one of the best implements a farmer has.

Rolling is very effective, provided the ground is in the right state and is not too wet; it is often omitted when it might economically be practised. It has three beneficial effects:—(1) It presses the young plant firmly into the soil and so stimulates root development; (2) it causes just sufficient injury to the stem of cereals or grasses to stimulate tillering; (3) it breaks up the crust that forms on a heavy soil in dry conditions, and leaves it in a more friable state. On light chalky soils, or after a ley, rolling is specially necessary, and the furrow presser then becomes a very valuable instrument.

No one can be recommended to give a dead fallow, though farmers on the very heavy London clays declare they cannot do without it. They may be right, but one would like to see the experiment of substituting stubble cleaning by tractor for a bare fallow. Where, however, a seeds mixture is thin or weedy, or does not promise a good second growth, it may be wise to break up after the first cut in June and give a summer fallow.

Fig. 12a.—Land Lost through Lack of Drainage.

This water does no one any good, and if the stream were kept clean and its drains maintained, much useful land would be obtained.

CHAPTER V.

WEATHER, CLIMATE, AND SYSTEMS OF HUSBANDRY.

Suitable temperature and water conditions are necessary for the proper growth of crops: both are determined very largely by the climate. The farmer can do something to mitigate the effects of too much or too little water and too hot or too cold a climate, but it is hard work fighting against Nature all the time, and the easiest—and therefore the most profitable—scheme of husbandry is the one in which the crops, varieties, and methods all suit the local conditions. Such a scheme involves, of course, a good system of transport, so that the products of the various specialised groups can be spread freely over the country; but it has the great advantage that a man sees a good return for his labour, for Nature, while a hard enemy, is a good ally.

Relations between Climate and Husbandry.

There are a few simple rules which afford guidance in determining the relations between climate and husbandry:—

(1) Dry climates favour seed and grain formation; they are also suitable for sheep. (Sheep do not like a wet winter, and they suffer more from wetness than from cold.)

(2) Moist climates favour leaf formation; they also suit bullocks and dairy cattle.

(3) Wet climates suit grass.

(4) Warm, early regions suit market gardens and special crops.

These rules are well illustrated in the maps of Figs. 12 and 13, showing the distribution of wheat and of grass in England and Wales. Wheat is a grain crop; it therefore flourishes best in dry conditions and so tends to concentrate in the Eastern Counties of England

where the rainfall is less than 28 or 30 inches—sometimes much less. Grass, on the other hand, flourishes in wet conditions, and is much grown in the western half, where the rainfall is higher. Dry conditions suit other seeds as well as wheat. The Eastern Counties produce mangold seed, turnip seed, mustard and clover seed, and many other seeds for farm and garden; this special industry assumes important dimensions in Kent, Essex, and other Eastern Counties. But no farmer can live on grain crops alone, and therefore the Eastern Counties farmer has to attempt some leaf crops, roots, etc. It is here that he generally loses money, and one of the best hopes for the Eastern Counties is to find something for the animals (needed for their manure) which shall be as good as roots and yet capable of givng better and more certain growth. Messrs. Amos and Oldershaw have experimented with silage and obtained promising results (Fig. 14).

Wetter conditions are favourable for leaf crops, such as roots, cabbage, rape, kale, vetches, etc., and for oats, because oats are cut before they are dead ripe. Hence we find husbandry in the West of England grouping itself around these crops, but leaving wheat alone. Still wetter conditions favour grass, and seeing that grass is entirely food for live-stock, it is not surprising that wet districts are given up very much to livestock raising. The principle is quite sound, but much improvement is possible. Many of these districts lie high and comprise a good deal of land which is now poor, receiving little attention and greatly needing basic slag. An essential preliminary to improvement is to enclose the grazing lands where they are still open. There are, for instance, parts of Wales where the grazing is common, each farmer having the right to turn out a certain number of sheep or cattle, but no right to erect a fence. This system is doubly bad: it is bad for the stock, because the herds cannot be kept

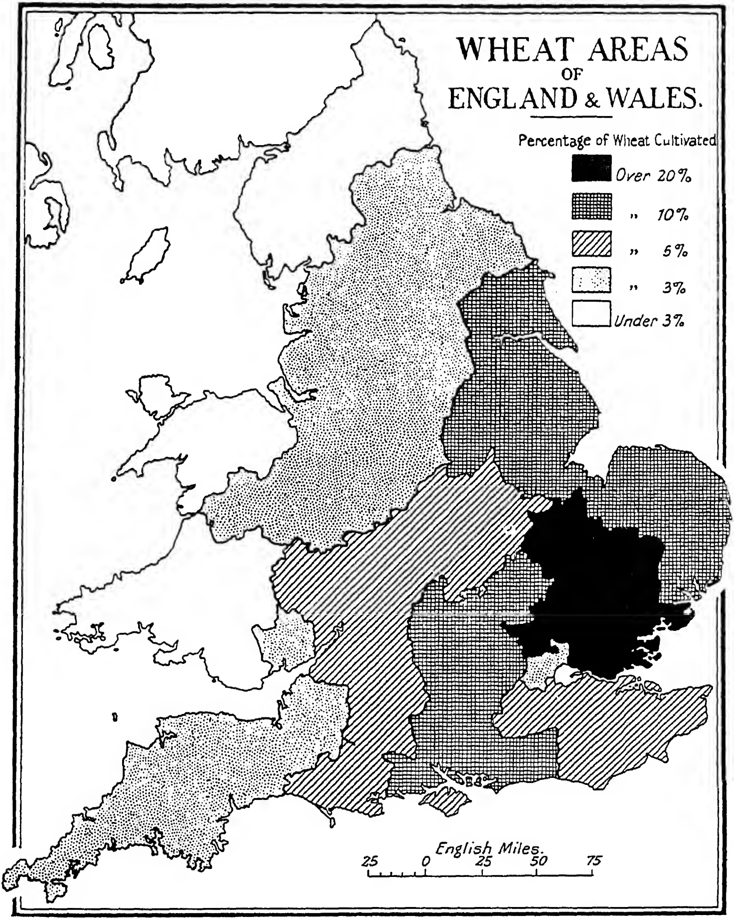


Fig. 12.—Distribution of Wheat Areas in England and Wales.

separate, and for the land, because so long as this lies open no one is likely to apply slag or attempt any drainage. But as soon as the fences are set up and kept in order, improvements in both directions become possible, and the standard of agriculture can be raised. Basic slag and the breed societies are doing much to increase the wealth of the wet districts.

Effects of Cold.

Cold operates, during summer, somewhat like excess of rain; cold districts are suitable for leaf crops and for oats, but not for other seed crops, and so we find wheat and seeds are little grown in the North. But in winter there is an important difference between coldness and wetness—coldness prevents the growth of weeds in winter, while wetness does not. The Scottish farmer prides himself, and with justice, on his good farming, but he ought to remember that his winters are very favourable to the farm, however execrable they may be to himself. When the spring comes his land is reasonably clean and he can go straight ahead with his cultivations, and with little trouble obtain crops free from weeds. On the other hand a farmer in the Home Counties, such as Herts, Surrey, etc., is liable to mild, wet winters, in which weeds can grow continuously in the winter corn, so that when the spring comes he is troubled with a growth that he hardly knows how to deal with. He cannot get over the difficulty by confining himself to spring corn as is done in the North, because he is liable to droughts which put spring crops out of the question. He may be able to deal with the problem by persistent stubble cleaning, but it is not completely solved yet, and many a Scotsman who comes into Herts, Essex, Bucks, Kent, or Surrey has found the weeds a troublesome nuisance. More than one very intelligent Scotsman farming heavy land in Essex is compelled to adopt the local practice of

periodical bare fallows, much against his wish, because the weeds are so much more persistent than under conditions of colder winters.

A further feature of the colder districts of the North is that the summers are cool, and consequently swedes and turnips make excellent growth. The average yield of swedes for Northumberland is 15 tons per acre, while a good farmer commonly reaches 25 tons and may obtain anything up to the 58 tons per acre obtained in 1918 on a well known Tweedside farm. Against these figures Herts can only show an average of 11½ tons; 16 tons would be considered good, while few, if any, farmers haxe exceeded 35 tons per acre.[1] The result is that the Northern farmer can rely much more completely on roots than a Southern farmer can. Further, in the North the oat does not ripen as completely as in the South, and consequently the straw retains more of its nourishing substances. The Northern farmer, therefore, has the double advantage of rich oat straw and safe large crops of roots. He can, therefore, dispense with hay for his sheep and fattening cattle; he needs some for his horses and his dairy cows, but he can commonly graze his seeds mixtures instead of cutting them for hay as the Southern farmer does.

Possibilities of Warm Climate.

Passing now to the opposite extreme, a warm climate is favourable for fruit and market garden produce, and many an alert farmer in the South has discovered the profitableness of this kind of husbandry, provided he can find and suit the market. One of the most interesting of these areas is near Penzance, where along the slope of a hill facing towards the south and south-east is a strip of land capable of bearing two crops a year—early potatoes, followed by broccoli—each of which may represent a substantial financial return. As

[1] The highest yield recorded at Rothamsted: obtained in 1922.

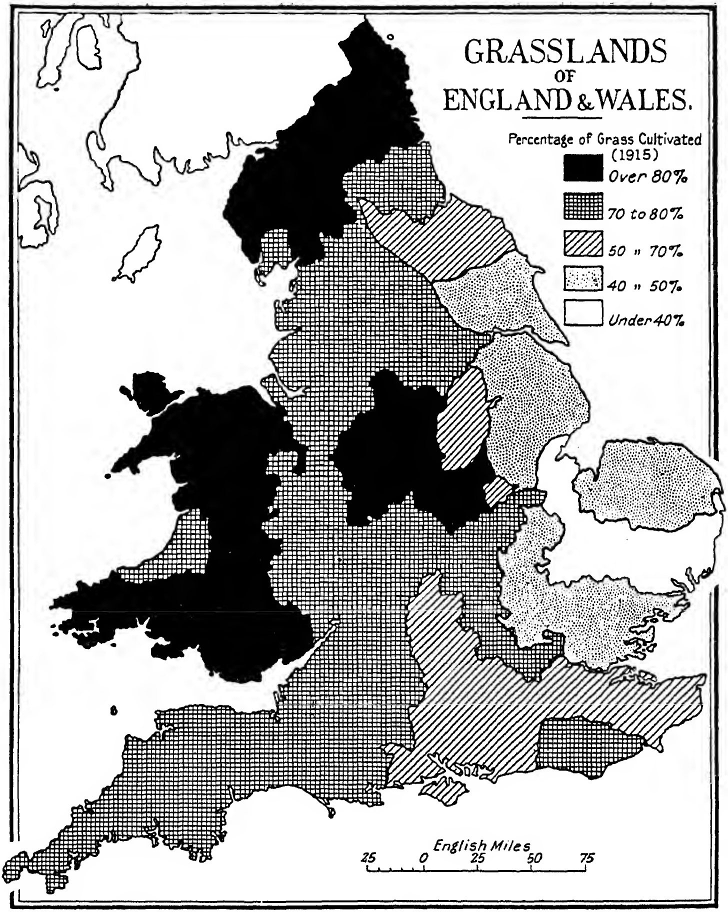


Fig. 13.—Distribution of Grasslands in England and Wales.

ordinary agricultural land, however, the returns would not be particularly large. Many areas in Hampshire of no great agricultural value have proved useful for strawberries for the Bournemouth and other markets; sandy districts in Bedfordshire, near the railway, grow onions and other vegetables with considerable profit, while the Evesham and Pershore districts are full of examples showing how valuable fruit, asparagus, spring onions, and other crops can become on land which is not itself specially fertile, but is blessed with a mild and favourable climate.

But there is one inexorable rule from which no deviations can be permitted. The grower must study the market, find out what will sell and when it will sell, then supply accordingly. It is no use producing material that is not wanted.

CHAPTER VI.

SOIL TYPE AND SYSTEMS OF HUSBANDRY.

If any one rule could be said to hold in husbandry it would be this—study the local conditions of soil, climate, etc., and make your farming agree with them as closely as possible. The best farmers have already done this and have developed a close connection between soil type and systems of husbandry.

LIGHT SANDY SOILS.

The chief failings of light sandy soils are dryness and sourness; the latter can be put right only by lime and chalk, and the dryness is remedied by a liberal use of organic manure, such as green manure, farmyard manure, sheep folding, etc. In addition, they lack potash so that they usually respond well to potassic fertilisers, or to the next best substitute, agricultural or fish salt. They are also very prone to weeds, and rapidly become foul if neglected. Against these failings are to be set three advantages: plants make very good root development, they ripen quickly and regularly, so that they yield seed of good quality, and sheep do well on dry soils. Several systems of cropping have been worked out to accord with these conditions.

Nursery Stocks and Shrubs.—Travellers on the L. and S.W. Railway are familiar with the industry which has arisen on the very light Bagshot sands skirting the railway and including Woking, Weybridge, Wisley, and many other well-known horticultural centres from which come a large proportion of the nursery stocks used throughout the United Kingdom. The light sand favours quick compact growth and great masses of fibrous roots; the shrubs have a good appearance and transplant well.

Market-garden produce. Earliness and quality are here desirable, and both are obtainable on light sands. Cultivation can be carried out easily at any time and in

Fig. 14.—The Silo. Of great assistance in helping out the troublesome root break in dry weather.

any state of the weather; growth is very quick. Roots, such as carrots, parsnips, etc., do well and look well; early peas and potatoes succeed, and by careful management two and sometimes three crops a year can be obtained. It is necessary to use plenty of stable manure. In the old days this was easily procurable from London and other cities; now supplies are much less. Where railway facilities exist and there is the possibility of obtaining the necessary manure this system is well worth consideration.

Sheep on Arable Land.

On large farms where market gardening is out of the question some system of husbandry becomes necessary, and advantage is taken of the fact that sheep do well on these dry soils during all except the summer months, when the soil may be too hot for them. It is, of course, impossible to rely on grass,and consequently a succession of arable crops is grown for them. Owing to the tendency to weeds the rotation is generally only a short one, usually four course, and it commonly consists of (1) roots and sheep feed; (2) barley; (3) seeds mixture; (4) winter wheat or spring oats.

Some very good farmers who can keep down weeds by cultivation are getting away from this four course plan, and they can do so as long as the land remains clean. Usually the variation is in the root break, and it all depends on whether a breeding flock is kept or a fatting flock. As an example of the breeding flock, the following may be taken; it is from a large farm in East Suffolk on very light land. The ewes have been in the marshes with the tups from the end of September till early or mid-November; they are then brought on to the arable land to a catch crop of colewort which was sown in June after the first cut of seeds; there they remain till the white turnips are ripe at the end of November. They stay on the white turnips till the

middle of April. Lambing begins about the first week in March, but from early February the ewes have had a little "bait" in the form of $\frac{1}{2}$ lb. daily of crushed oats, bran, and a little linseed cake. About mid-April the ewes and lambs go on to coleworts sown in the previous August to stand through the winter; this crop causes a good flow of milk. Here they stay till the middle of May, then they go on to a mixture of oats and tares till the middle of June, then to coleworts again to give a little bloom to the lambs before the sale in early July.

As an example of a dry or fatting flock, the following is from a Surrey farm. Sheep are brought in in September and fattened out during the winter, a certain number being drawn each week for market; the whole lot are cleared out by the end of April, there being no grass to tide them over the summer. Various green crops are grown; swedes and kale (six rows of the former and two of the latter), rape, green rye, winter barley, etc. A considerable amount of cake is fed so as to get the animals out early while prices are still good.

Variations on Chalk Soils.

On chalk soils the position is somewhat different because they are cooler in summer, and there is no need to get the animals away so early. In a large breeding flock in Dorsetshire the following scheme of cropping is arranged. Lambing takes place in January and February, and the lambs are sold in August. Sowings are made in May of rape, mangold, hop clover, and rye grass; in June of turnips and rape mixed indiscriminately, turnips alone, swedes alone, swedes and kale—four drills of the former to six of the latter; in July, kale; in August, cabbage (garden sorts, not the Drumhead, this variety being reserved for the cows), early red trifolium, late white trifolium; in September, winter barley, rye, first sowing of winter

Fig. 15.—Potatoes on a light soil. Quite a suitable crop so long as the expense does not become too great.

vetches; in October, more winter vetches, cabbage; then in the spring, say in March, a mixture of vetches, oats, and peas. This is an extensive list, but the breeder cannot afford to leave anything to chance.

The areas devoted to each crop have to be thought out carefully so as to avoid unnecessary work and trouble. While provision has to be made against possible failures, it is also necessary to have some way of using up possible excess; here the silo comes in very useful. Any crop not wanted by the sheep can be cut up and blown into the silo, where it will keep for a long time, and can be fed to other animals, for the breeding flock will not take silage.

No strict rotation is kept, but it is not usual for the land to be "sheeped" too often; and in the intervening period corn crops can be grown. Thus, of the 700 acres of arable land, 250 acres are under corn crops (mainly wheat and oats), and 14 acres under potatoes. As might be expected, the corn crops do very well following crops eaten on the field by the sheep, though they are noticeably poorer after mangolds drawn off for the cows.

There is, however, a marked tendency for the dairy cow to displace the sheep on the chalk soils, and this necessitates the abandonment of folding and some change in the cropping. It remains to be seen whether the fertility of the chalk soils can be adequately maintained without sheep: certainly the production of farmyard manure must be less, since one cow displaces many sheep: in Hampshire and Wiltshire one cow has, during the past thirty years, taken the place of 9 sheep: in Berkshire of 15 sheep: and over the whole country of 11 sheep.

Fertilising Elements Required on Chalk Soils.

In many cases corn crops require little fertiliser, except some superphosphate to counteract the effect of

excess of nitrogen after the folding. If the climate allows of good yields it may be desirable to give a little nitrate of soda or sulphate of ammonia to a second corn crop. Corn and leguminous crops often respond to potassic fertilisers—notably kainit—and crops grown for sheep are often improved in feeding value by the use of superphosphate or basic slag. Lime is often necessary on soils overlying the chalk, and it can go on before the seeds. Farmyard manure is essential, and is used for the roots or the wheat or spring oats.

On some of the poor light land it is possible to grow only lupins for ploughing in, and then rye; but this system necessitates two years' work for a single crop.

HEAVY SOILS.

The disadvantages of a heavy soil are difficulty of cultivation, harmful effect of rain in autumn, winter, and summer, injury done by spring droughts, and unsuitability for sheep. Against these may be set adaptability to cattle, special suitability to grass, wheat, winter oats, beans, mangolds, and some of the modern silage mixtures. Further, there is less liability to weeds than on light land, although in certain conditions weeds become a great nuisance.

The present position of clay soils has arisen largely out of their past history. In the old days they were used for wheat and beans; cultivation was brought about with heavy wooden ploughs that look very cumbersome and antiquated to a modern farmer, but nevertheless were very effective, and, inded, sometimes did better work than some of the modern substitutes. So long as labour was fairly cheap and prices sufficiently high it was possible to continue a simple rotation with the aid of occasional bare fallows. When the depression came some forty years ago the heavy land went down to grass, and, as a certain amount was

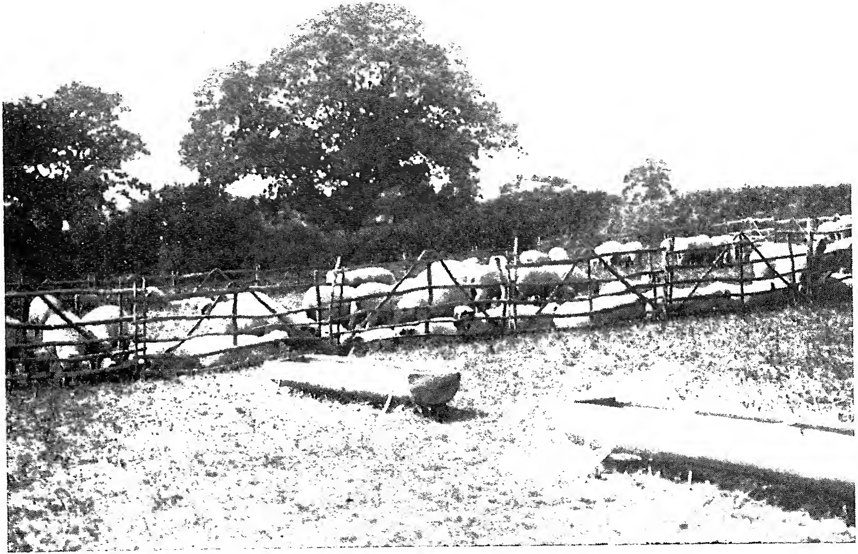


Fig. 16.—Sheep folded on Arable Land. An excellent way of keeping up soil fertility.

already devoted to this crop, the proportion of grass to arable became very high. By means of livestock, farmers managed to obtain some sort of living, but the returns per acre were only small, and there was no scope for the employment of much labour.

The general result of the history of heavy land is that a good deal is already in rather unsatisfactory grass. Two courses are open :—(1) The grass may be improved, or (2) it may be converted into arable.

Improvement of Grass.

Two methods exist for the improvement of grass land, treatment with basic slag and drainage. Sometimes slag alone is sufficient, sometimes both are needed, but it nearly always happens that one or both must be used. Addition of slag has had a most wonderful effect on the heavy land of England, especially the poor land carrying only thin herbage with a great deal of bare space on the ground. In almost every county experiments have demonstrated this remarkable effect. The pioneers were Prof. Somerville at Cockle Park, in Northumberland, Sir T. H. Middleton, and Prof. D. A. Gilchrist, then at Bangor with Sir J. J. Dobbie; the work was continued by these gentlemen in various centres all over the country, and now every farmer knows the story. But there still remain men who do not improve their grass, in spite of the fact that the additional herbage enables them to carry more stock, and to turn out their stock more quickly than was possible before. Even under the dry conditions obtained in Essex, slag is found to be very effective, and Prof. Scott Robertson's experiments there are among the most striking that have been made.

In certain cases lime is necessary before the slag can act: instances occur in Yorkshire.

It often happens, as at Cockle Park, that wettish land becomes sufficiently dry after treatment with slag,

thus rendering drainage unnecessary. In many cases, however, there is so much free water that a way out has to be found and some system of drainage must then be adopted. Mole drainage is often useful, and it should be inquired into before pipe drainage is attempted.

Conversion into Arable.

While arable land is more expensive than grass to farm, and therefore more risky in times of falling prices, it produces more food per acre, as is shown by the following table :—

	Yield in tons (less seed) (Great Britain).		Energy value of food. (Millions of calories.)		No. of days for which 1 acre will provide for one man.
	Crop.	Flour.	Per ton.	Per acre.	
Potatoes	5.4	—	0.96	5.16	1.500
Wheat	.80	.64	3.7	2.38	790
Barley	.73	.43	3.9	1.68	490
Oats	.62	.41	3.9	1.60	470
Meat from :—					
Rich pasture	190 lb. fat meat.		5.66	.49	140
Medium pasture	100 lb. lean meat.		2.96	1.3	40
Poor pasutre	20 lb. lean meat.		2.29	.02	6
Milk rom good grass	2000 lb. milk. 45 lb. meat.		.74	.67	200

As an example of heavy land arable farming in the southern part of England, it is found at Rothamsted that winter corn usually succeeds, barley is generally good, spring oats and spring wheat are usually unprofitable, potatoes do tolerably well, as do mangolds, except in a dry season, and swedes and turnips generally do badly. In drawing up the rotation, therefore, as much as possible of the land is put into winter corn and only the minimum area into roots. Cleaning of the land is done by means of the autumn cultivation and stubble cleaning already described. The weakness of the system at present lies in the root-break : a portion of the land must always come into roots, and we have as yet found nothing that invariably pays — potatoes have been profitable, but they have also led to serious

Fig 17.—Chalk on sour sandy soil. This and green manure constitute two very important improvements.

losses; swedes and turnips have failed, and mangolds have often barely repaid expenses.

There is no doubt that the future of this rather heavy land over much of the country depends on the root-break; it is here that money is lost, and if only this could become self-supporting, the finances of the farm would be considerably uplifted. Mr. J. C. Brown at Mr. E. D. Simon's Leadon Court Farm, now associated with Rothamsted, is doing valuable work on this problem, and farmers should carefully study his series of crops designed to feed a dairy herd throughout the year.

The other crop that deserves attention is the seeds mixture; pure clover is sometimes attempted where a mixture would be better, and every often the mixture could be much improved. It is impossible to give any general instructions, but the County Organiser should be consulted in cases of uncertainty. Often, too, loss is increased because the seeds need lime or chalk.

Special Types of Soil.

Fen Soils.—Owing to their limted area and the good type of farming that generally prevails, it is unnecessary to say much about these soils. They are almost exclusively in arable cultivation, and little or no live-stock is kept. The most suitable crops are oats, wheat, and, above all, potatoes, the introduction of which some thirty years ago completely revolutionised fen husbandry. In smaller quantities mangolds, celery, mustard seed, cole seed, rye grass seed, buckwheat, and other seeds are grown. Corn crops, however, do not finish well; they start well but do not "corn out." But where clay lies underneath, a complete remedy lies in bringing up the clay and spreading it; this is done about once in twenty years. The soil shrinks very much on drying, forming large cracks dangerous to animals and sometimes destructive to cart-wheels.

Oxidation is continually proceeding at a rapid rate, and within living memory the fen has shrunk several feet —in many cases it only has another 5 feet or 6 feet to fall before disappearing altogether.

Fen soils do not require lime or nitrogenous manures, or, as a rule potash; but they do respond in a marked degree to superphosphate, and in ordinary practice no other fertiliser is used.

Peat Soils.—These differ from the fen soils. A distinction must further be made between the high-lying and the low-lying peats. The high peats are usually subject to so heavy a rainfall that ordinary agriculture is impossible and only a small area can be put into oats, rape, or similar hardy crops. In the past farmers often bought their corn, but there is no doubt more could be raised locally, and there are considerable possibilities in some of the new varieties now available. Superphosphate should always be used to hasten ripening, and a little nitrate of soda or sulphate of ammonia is useful in giving an early start. The grass is often greatly improved by slag. In all cases, however, cost must be carefully studied and improvement effected slowly; it is very easy to spend more money than will ever come back.

For *low-lying peats* three broad methods of treatment have been adopted :—

(1) Ameliorating substances (such as lime, artificial manures, etc.) are added, and the peat is cultivated as if it were normal soil, potatoes and oats being specially suitable crops. This is possible only when the deposits do not lie too high.

(2) The peat is removed and sold, and if the climate allows, the underlying formation is :—

(*a*) Ploughed up, if it is clay or sand;

(*b*) Covered with town refuse and then cultivated, as at Chat Moss.

Fig. 18.—Oats grown on moorland treated with the proper fertiliser. A valuable Swedish experiment by Prof. von Feilitzen.

(3) The ground is warped—that is, systematically flooded with tidal water carrying silt till several feet of soil has been formed; this is possible only in a few areas, e.g., Lincolnshire, lying below high-water level.

CHAPTER VII.

CONTROL OF SOIL FERTILITY.

In the preceding chapters it is shown that following conditions are necessary for success :—

(1) The crops must suit the soil and the climate;

(2) The system of husbandry—i.e., the method of growing and disposing of the crops—must suit the local conditions and the markets;

(3) Given suitable crops, failure may still result from :—

- (*a*) Insufficient plant food;
- (*b*) Insufficient water;
- (*c*) Insufficient air for the roots;
- (*d*) Too low a temperature;
- (*e*) Too little root room;
- (*f*) Some harmful quality in the soil or some plant disease.

LET CROPS SUIT CONDITIONS.

Farmers are now in a better position than ever before to find varieties of crops specially suited to their local conditions, and on many farms it would be possible to increase yields appreciably without spending another penny on manure or cultivation by simply substituting a new variety for the one usually grown. Instances could be multipled all over the country; to take one, Mr. Lindsey Robb, at Newton Rigg, has grown different varieties of crops side by side, giving each the same cultivation and manure; some of his results are :—

	Ordinary local variety ; yield	Newer variety better suited to the farm ; yield
Oats	45 bushels	Up to 70 bushels
Swedes	25 tons	36 tons

Because a variety does well on one farm it does not follow that it would prove the best on another even in

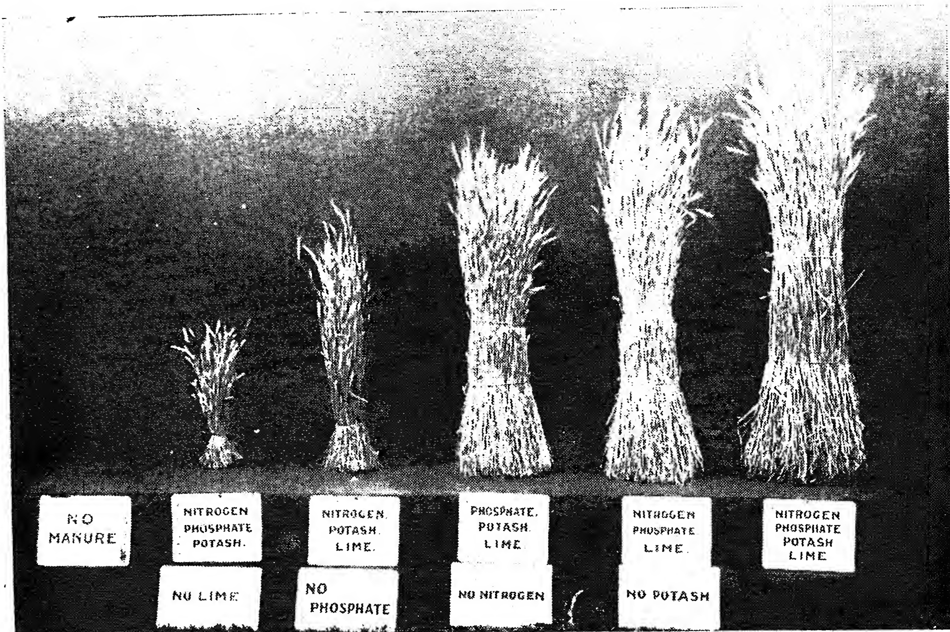


Fig. 19.—An interesting Irish experiment. On this peat soil nothing could be grown until lime and fertilizers were added; then an excellent growth of oats was obtained, as shown above.

the same district: it may, or it may not, nothing but actual trial will show. When it comes to districts widely separated the varieties may come out in a very different order of merit as the results following prove:—

	Glasgow		Cambridge	
	Yield per acre	Order	Yield per acre	Order
	Bushels		Bushels	
Wide Awake	64.2	1	56.5	6
Waverley	62	2	70	2
New Abundance ..	59.5	3	65.5	5
Banner	58.7	4	70	2
Thousand Dollar ..	56.2	5	71	1
Siberian	54.2	6	70	2

Careful watch should therefore be kept for new varieties, but they should not be given on the large scale till they have proved satisfactory in small tests.

Just as the farmer can change his crops to suit his conditions so he can change his conditions to suit his crops, though to a far smaller extent. The effects of bad climate may be mitigated; wetness is made less injurious by drainage and cultivation as shown in Chapter IV., and its retarding effect on plant growth and on ripening may be lessened by giving a little nitrate of soda or sulphate of ammonia to ensure an early start, and sufficient phosphate to hasten the ripening. Dryness can be overcome completely by irrigation, and partly by surface cultivation, the addition of farmyard manure, green manure and the treading of sheep, all of which will be discussed later, while its effects are diminished by potassic fertilisers which keep the plant growing longer than it otherwise would.

Control of the soil by cultivation has already been discussed: it remains now to show how fertility can be controlled in other ways.

Food Supply on Arable Land.

All fertilising constituents absorbed by a crop that is carried away are lost to the land, and whatever is thus

removed obviously cannot be counted upon for future crops. Table I. shows the amount of plant nutrients removed by ordinary sized crops from land in medium condition; a 22 ton mangold crop (roots only) is seen to take 98 lb. nitrogen, 36½ lb. phosphoric acid, and 223 lb. potash, while a 30-bushel wheat crop removes in the grain only 34 lb., 14 lb., and 9 lb. respectively of these substances. For this reason the mangold crop is said to be exhausting, and farmers will often declare that in the corn crop they can see to an inch where the preceding crop was mangolds which were drawn off. In the old days these occurrences caused a good deal of trouble, and restrictions of various kinds were introduced into leases, but nowadays they present no particular difficulty; the absorbed constituents can quite well be replaced by artificial fertilisers, and the exhaustion is then rectified.

There is now no justification for restrictions as to cropping, sale of crops, etc., since it is quite easy to make good any losses from the soil. Table I., however, does not afford a complete guide to the loss of fertiliser constituents brought about by arable cropping, for losses arise not only from the crop, but from drainage as well. These latter losses are small and almost negligible for potash and phosphates; they become much greater for lime, and, in regard to one of the most important constituents, nitrogen, the loss from drainage and dissipation commonly exceeds the loss from actual cropping. Fig. 20 illustrates the results from Broadbalk; similar results have been obtained elsewhere. It follows that a farmer who simply replaced what he took away would impoverish his soil both in lime and nitrogen. This is shown on one of the Broadbalk plots, which each year receives potash and phosphates in addition to 43lb. nitrogen per acre (as sulphate of ammonia). Now 43 lb. is the quantity of nitrogen taken by a 26 bushel wheat crop; one might

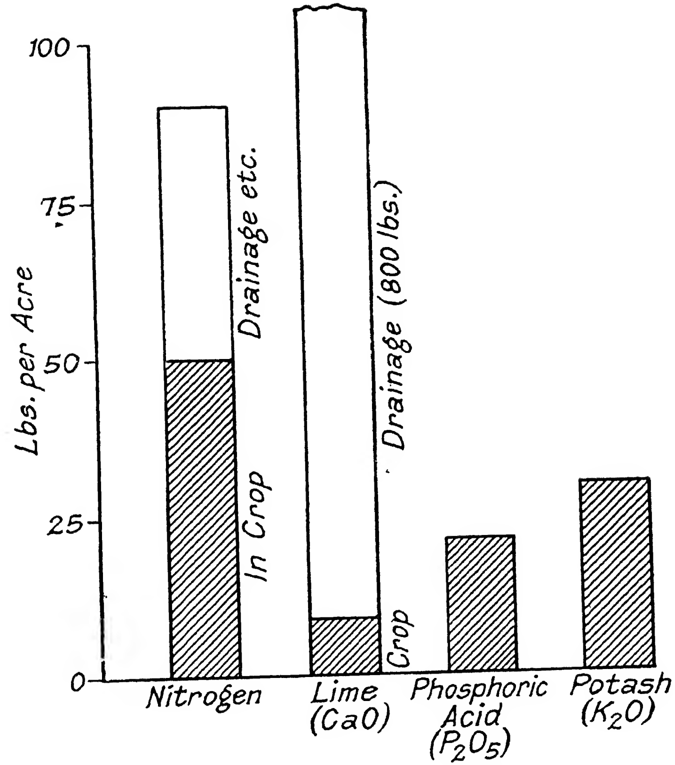


Fig. 20.—Diagram showing the wastage of fertiliser constituents from the soil. Broadback Wheatfield. The greatest loss from the point of view of quantity is in the lime. Most of this is brought about by drainage water. The most expensive loss is in the nitrogen, half of which is due to the crop, and half to drainage water. The loss of phosphate and potash is small and entirely due to the crop.

expect therefore that this yield would be attained. It is not, however. For the past ten years (1911-1920) it has been 21.9 bushels only, and it is steadily falling at the average rate of 1 bushel in seven years.

The reason for this loss of nitrogen lies in the activity of the soil organisms already described. There is a constant process of change in the soil whereby nitrates are formed: these are invaluable as plant food, but, unfortunately, they are very rapidly lost by drainage or destroyed in other ways. Lime is lost because it dissolves in water in presence of the carbonic acid given off into the soil by the plant roots and the processes of decay. Potash and phosphates suffer no loss apart from cropping—a fact of great importance in fertiliser practice.

TABLE I.

Fertilising Constituents Removed by Average-sized Crops. Lbs. per Acre.

	Nitrogen (N)	Potash (K_2O)	Phosphoric acid (P_2O_5)
Wheat, Grain, 30 Bushels	34	9.3	14.2
,, straw	16	19.5	6.9
Total crop	50	28.8	21.1
Barley, grain, 40 Bushels	35	9.8	16.0
,, straw	14	25.9	4.7
Total crop	49	35.7	20.7
Oats, grain, 45 Bushels	34	9.1	13.0
,, straw	18	37.0	6.4
Total crop	52	46.1	19.4
Meadow hay, 1½ tons	49	50.9	12.3
Red clover hay, 2 tons	98	83.4	24.9
Swedes, root, 14 tons	70	63.3	16.9
,, leaf, ,,	28	16.4	
Total crop	98	79.7	21.7
Mangolds, root, 22 tons	98	222.8	36.4
,, leaf, ,,	51	77.9	16.5
Total crop	149	300.7	52.9
Potatoes, tubers, 6 tons	46	76.5	21.5

A further effect of arable cultivation is to exhaust the supply of organic matter in the soil. So long as there is sufficient organic matter the water supply and air supply are likely to be good, and the cultivation processes can fairly easily be carried out. But when the organic matter falls too low cultivation becomes more difficult, tilth is not easily obtained, and air supply may be reduced. Crops such as potatoes that require plentiful air supply to the roots can be grown only with difficulty, and are best not attempted.

Food Supply on Land in Grass or Seeds Mixture.

Compare all this with what happens under grass. Drainage is reduced to a minimum, and there is no washing away of plant food. No great amount of fertilising material is carted off; even where hay is sold the aftermath is usually grazed, and the crop removes from the soil little more than a crop of oats. Further, even in this case there is no net loss of nitrogen from the soil; often, indeed, a gain, since the clover organisms fix nitrogen from the air, as already described. In addition, there is a great gain in organic matter which has been made by the plant from the air. These facts are all illustrated by the following analytical figures obtained at Rothamsted and in Canada respectively:—

Up Grade—Arable Land laid down to Grass (Rothamsted).

	Original	After 23 years	After 32 years	After 56 years
Nitrogen	0.15 per cent.	0.20 per cent.	0.24 per cent.	0.34 per cent.

Down Grade—Virgin Land converted to Arable (Canada).

	Original	After 22 years cultivation.
Nitrogen per cent.	0.27	0.75
,, lb. per acre	6940	4550 Loss = 2190 lb. per acre

The accumulation of nitrogen and organic matter while the grass is growing is somewhat slow, but it keeps on for a long time. During the early years newly-sown grass commonly yields well, then it falls off, and finally improves again to give a good "old pasture." When the grass is broken up the accumulated fertility is released, and so we can understand the advantage of taking arable crops after grass and appreciate the popular saying, "Make a pasture, break a man; break a pasture, make a man."

Of course it does not invariably follow that the first crop after ploughing up the grass is profitable. It may happen that a satisfactory tilth could not be obtained, that the ploughing was done too soon or too late, the grass was not properly killed, or the ground insufficiently consolidated. In districts of rather low rainfall, 26 inches or less, consolidation is very necessary, and instruments such as the furrow-presser should be used if cereals are taken directly after grass. In such circumstances potatoes are probably the best crop.

The facts are illustrated by the results obtained from ploughing up grassland in 1917. In spite of the fact that much of this land had gone down to grass because it was unsuitable for arable purposes, it nevertheless gave in 1918 higher yields of potatoes, mangolds, and turnips than the older arable land, but it gave lower yields of cereals. Oats did best, then wheat, and then

	1918			1919		
	Estimated yield on new arable.	Average yield England and Wales.	Yield on new arable when average for England and Wales = 100.	Estimated yield on new arable.	Average yield England and Wales.	Yield on new arable when average for England and Wales = 100.
	Bushels	Bushels		Bushels	Bushels	
Wheat ..	31.3	32.9	95.1	28.4	28.7	98.9
Barley ..	28.8	32.4	88.8	28.0	29.0	96.5
Oats	40.7	41.3	98.5	36.6	35.6	102.8
	Tons	Tons				
Potatoes ..	7.1	6.6	107.6			

barley (this was also the result of the Rothamsted trial). In the second year the yield of cereals improved; oats were better than on the old arable, and wheat was practically the same both on old and on new, while barley was only a little behind. The results are shown in the table on page 53.

Plant Food Supply: How to Increase It.

Of all factors in soil fertility the supply of plant food is the easiest to control. The farmer now has available to him an extensive list of substances—no less than thirty—which add any desired constituent to the soil. The real difficulty is to know just what to add.

It used to be supposed that an analyst could take a sample of soil, make some chemical tests, and then say exactly what constituents were lacking, and how much of each would be necessary to put matters right. It is possible to point to cases where success has been achieved; but there have been many failures, and most agricultural chemists now recognise that soil analysis is of value only in comparing one soil with another that is very much like it. Thus, if an analyst knows that basic slag acts well on A's farm, he can advise B, whose soil is very similar, whether slag is likely to act well for him. But without this detailed knowledge of actual farm results an analyst cannot give very useful advice.

Farm Tests Needed.

The soundest information comes from actual farm tests. The individual farmer may be in no position to make these, but county authorities, farmers' clubs, Chambers of Agriculture can do so. The simplest plan is to set out varieties in one direction and manurial treatment in another. As an example the following may be given. It was not carried out at an experimental

station, but on a farm, and not by a professional experimenter, but by a practical farmer:—

Trials with Oats on Poor Light Land, Shrublands Park Estate, Suffolk. Yields per Acre.

Manures per acre	Waverley Grain bush.	Waverley Straw cwt.	Abundance Grain bush.	Abundance Straw cwt.	Record Grain bush.	Record Straw cwt.	Tartar King Grain bush.	Tartar King Straw cwt.
No manure ..	18½	17	22	15	18	16	17	16
1¼ cwt nitrate of soda	29	27	26	19	25	20	23	17
1¼ cwt. nitrate of soda +2 cwt. super-phosphate	30½	26	25½	22	29	23	23	21
1¾ cwt. nitrate of soda +2 cwt. super-phosphate + 15 cwt. ground lime ..	28	26	24	23		26	22⅓	19
15 cwt. ground lime ..	15	13	13	11	19	16	12	9
15 cwt. sulphate of ammonia + 2 cwt. superphosphate ..	28½	22	27½	18	26	21	22½	19

The test gives just the information the farmer needs; it tells him that nitrate of soda gives a very distinct return, increasing the yield by anything up to 10 bushels of grain and 10 cwt. per acre of straw, while further additions of superphosphate, and of super and lime, do not further increase the crop—not necessarily because they are not wanted, but probably because they have no chance of acting. Of the four varieties tried, Waverley has come out best.

Such a test should always include a limed plot; there are many cases where time and money are being largely wasted because the soil needs lime, and *nothing else will do instead.*

Control of Water Supply.

In dry seasons large parts of England suffer from lack of water, and therefore it is necessary to make the most of the existing supply, particularly in view of the impossibility of adding any more water to the soil of the ordinary farm. This can be done in three ways:—

(1) By adding organic matter to soil—e.g., farmyard manure, green manure, clover residues, etc.

(2) By surface cultivation, which reduces evaporation.

(3) By keeping down weeds, the worst soil-robbers in existence.

The effect of organic matter is shown in Fig. 21. Addition of farmyard manure to the soil causes an increase in the power to hold water, which we cannot yet reproduce by any combination of artificials; the result is that soil receiving farmyard manure is always a little moister than soil which does not. On the mangold field at Rothamsted, the part that regularly receives farmyard manure always contains more water than the part that receives artificials only. During a dry spell this additional moisture means a great deal to the young plants, so that they develop well; those without farmyard manure have abundance of food, but they lack water, and make so little growth that they fall a long way behind. Of course, when the rain comes they pick up satisfactorily, but no farmer likes to see his plants standing still waiting for weather. Farmyard manure is therefore of great importance in the Eastern counties. Most farmers, however, have insufficient farmyard manure for the purpose, and there are two courses open to them, namely:—(*a*) Green manuring; and (*b*) grass or clover leys.

Green Manuring.

This is recognised as one of the most effective ways of improving soil. In the old days farmers sometimes gave a whole year to it, but this is no longer necessary if a man has a tractor. The green manuring crop can be got in between two other crops, *provided the work is done quickly enough*. As an example:—In June, 1920, the clover on Great Knott field, Rothamsted, was weedy in consequence of plants dying in the winter; the first cut was therefore taken as early as convenient and the land *immediately* ploughed; mustard was sown and came up well, growing thickly and smother-

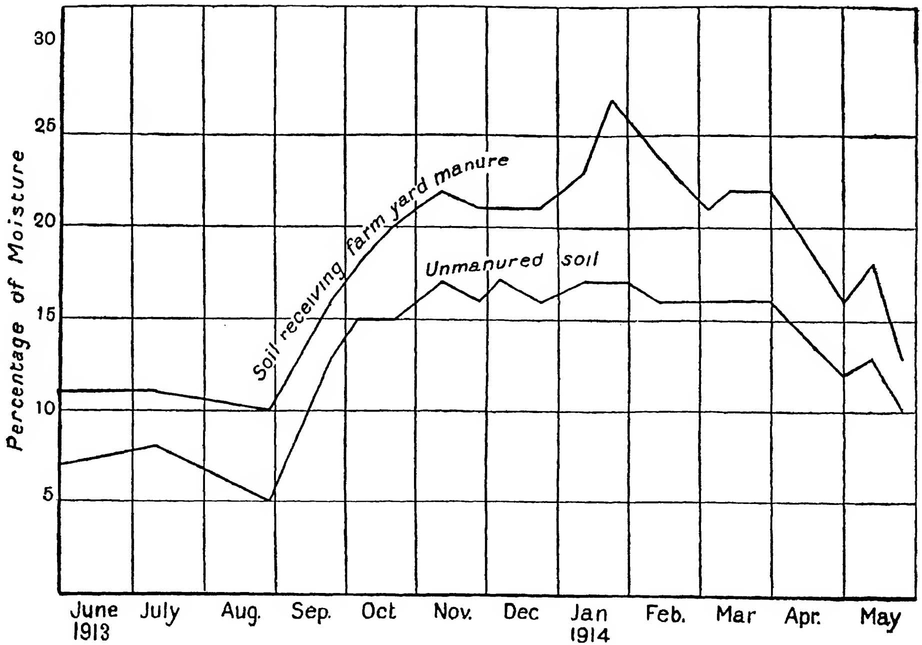


Fig. 21.—Diagram showing the amount of moisture in a soil supplied with farmyard manure compared with a soil receiving artificials only.

ing the weeds; it was ploughed in in September and oats sown. In spite of the drought of 1921 this crop did well; without any further manure it yielded 50 bushels of oats and a ton of straw to the acre, and with a dressing of artificials the yield of grain rose to nearly 60 bushels.

Speed of working, however, is very important. Land which has carried a crop may be sufficiently moist to allow of the germination of seeds if it is cultivated at once, but after the crop has been cleared off and the surface exposed to the sun and wind it may become so dry that germination is impossible. Mustard sown in this way is of great value on chalk soils; it is more effective than any combination of artificial manures and fully as good as a heavy dressing of well-made farmyard manure. Another useful crop is trifolium, which has the advantage that the young plant will tolerate a firm seed bed, so that it can be drilled on to a stubble with very little preparation. Where the crop will stand the winter it can be left over till spring; otherwise it must be ploughed in in autumn. On very light sandy soils nothing is better than lupines, which will tolerate both dryness and acidity. Tares are an excellent preparation for wheat on heavy soils, but they are not suitable on sandy or chalky soils. Various other crops will serve as green manure; in all cases local knowledge is required.

Advantages of Alternate Husbandry.

The other method for increasing the supply of organic matter in the soil is by ploughing in grass or clover residues. We have already seen that grass husbandry increases soil fertility, while arable husbandry uses it up. As a general rule, therefore, the farmers best course is to practise alternate husbandry —that is, some years in grass and some in arable. During the grass period valuable nitrogen and organic

matter are being stored up in the soil, and in addition the farmer is receiving a safe return on his outlay, and during the arable period the nitrogen and organic matter are being worked out and good crops can be obtained. The temporary grass commonly grown gives larger yields per acre than the permanent grass, and it can be broken up as soon as it begins to deteriorate, while the presence of the grass and clover residues often makes all the difference between success and failure on arable land.

There are many good mixtures. Our object is not so much to recommend a particular one as to emphasise the fact that *alternate husbandry is usually best!*

CHAPTER VIII.

CONTROL OF SOIL FERTILITY (*Cont.*).

VALUE OF SUBSOILING.

All farmers know that if they took on more land they could get more crops, but they do not always realise that they could often extend their farms downwards and secure more soil without paying any further rent, rates, or taxes. In many cases the soil is used only to a depth of 5 inches, whereas it could quite well be cultivated to 10 inches, thereby adding considerably to the resources of the farm.

The advantages of subsoiling were shown some 10 or 15 years ago by the experiments of Mr. F. J. Gurney, of Ridgewell Hill, Halstead, who was at that time farming on the heavy land in Essex, which by ordinary methods yielded only poor crops. For many years it had been ploughed with the wooden plough to a depth of a few inches only; there had been no deep ploughing at any time, and the result was the formation of a dense ploughsole at a depth of about 4 or 5 inches below the surface. This was as hard as the driest of clods, and no plant roots could possibly get through it. Mr. Gurney sent the subsoiler behind the plough so as to tear up this ploughsole, and thus gave his crops considerably more forage ground than they had before. The result was strikng—all the crops were benefited, and considerably increased output was obtained at comparatively small expense.

These results were confirmed at Rothamsted, using Mr. Gurney's subsoiler, which was drawn by horses and sent behind the ordinary plough. Potatoes were grown and gave half-a-ton per acre more than without subsoiling. This was in 1914. In the succeeding year —1915—the wheat crop also benefited. This was a bad year for wheat and the yields were low, but more grain and more straw were produced by subsoiling than

where this was not done. The winter oats of 1916, however, and the wheat of 1917 showed no benefit. The experiment was repeated with potatoes in 1916, and again an increase of half-a-ton per acre was due to subsoiling. The results were:—

	1914 Potatoes.		1915 Wheat.			1916 Winter Oats.			1917 Wheat.	
	Tons per acre.		1	2	3	1	2	3	1	2
Subsoiled in 1914 ..	7.4	Grain bus. per acre	20.3	19.4	16.4	30.5	30.9	29.3	19.0	21.5
		Straw, cwt. per acre	20.8	18.8	21.2	20.9	21.1	23.0	16.2	17.9
Not subsoiled ..	6.9	Grain, bus. per acre	19.1	15.5	13.7	29.4		33.3	22.2	19.1
		Straw, cwt. per acre	21.0	16.3	15.8	20.5		19.5	17.9	15.9

These results were obtained on land which had been deep ploughed and where no definite ploughsole had been formed. On many heavy-land farms, however, there is a ploughsole, and much more striking benefits are derived.

Essex still affords some of the most striking instances of the benefits of subsoiling. The farm of Mr. J. Hepburn at Bradfield Hall, near Mistley, was in a bad state when taken over, but now by good management it is very productive, subsoiling playing a great part in the improvement. This process is carried out with the tractor and not with horses or steam tackle. The ordinary tractor will not move the subsoiler; the wheels simply spin round and the machine buries itself in the soil. Mr. Hepburn uses a tractor which, though drawing only one furrow at a time, covers 1½ acres per day and does the work thoroughly.

The crops on the subsoiled land are not only better than those on the land which has been simply ploughed, but they are cleaner and weeds are kept down with less expenditure on cultivation.

Removal of Harmful Substances or Agents.

There are many possible harmful substances, and the farmer would need to be a good chemist to know them all. But one thing for which he ought to be very thankful is that lime, limestone, or chalk come as near to being a universal remedy as is possible. A number of obscure troubles are grouped under the general name of sourness, but they are all remedied by limestone or chalk. We shall discuss later on the differences between these substances; they are, however, matters of detail rather than of general principle. All over the country and on all types of soil one finds examples of infertility arising from sourness. The land may be drained, cultivated, manured, and yet not be as productive as it should; there are bad patches where the crop is unhealthy and it readily succumbs to an adverse season. After treatment with lime, or one of its equivalent substances, good results are obtained. In Norfolk and Suffolk the crag is a convenient source of these substances.

In other cases loss of crop arises from fungus and insect pests. It is not our purpose to deal with these except to state that the attack of such pests is affected by the system of husbandry. Thus in the West Country it often happens that out of eight years' cropping, six or seven are grass or cereals. Now grass and cereals are likely to be attacked by the same things, so the conditions may favour the continuance of pests on the farm. Again, some varieties are less susceptible than others; of the leguminous plants some of the red clovers are readily attacked by the eelworm, *Tylenchus*, while Alsike, Wild White clover, Sainfoin, and Lucerne are much less liable to suffer.

Consult the County Adviser.—There are, however, many cases where a field or part of a field remains infertile, in spite of all that is done. It may be faulty

subsoil, or there may be some quite unexpected defect. In that case the best thing is to consult the County Adviser, whose address can be obtained on application at the County Council offices.

CHAPTER IX.

NATURE AND FUNCTION OF MANURES.

Manures are substances which are added to the soil in order to increase the growth of crops. The older writers made a rather fine distinction between substances like Lime which improve the soil, and those like Nitrate of Soda which feed the crop, calling the former " soil amendments " and the latter " manures proper." It is now recognised that the distinction is not really valid. Lime and Farmyard Manure certainly improve the soil, but they also furnish food for plants; while Nitrate of Soda, though a valuable food, has also direct effects on the soil.

It is now recognised that all manures have a complex action in the field:—(1) Feeding the crop; (2) Altering its habit of growth, its feeding value, its qualities, market price, etc.; (3) Acting on the soil and affecting tilth, moisture-holding capacity, draft of implements, etc.; (4) Making the soil acid or alkaline, according to the nature and circumstances of the case.

It is important to bear in mind these complex effects, because they explain a fact which is familiar to all observant farmers, namely, the very variable action of manures on different farms and in different seasons. It is probably not too much to say that no two applications of manure ever give quite the same result, even though they represent equal quantities of the same manure used on the same crop. Results over an average of seasons can, of course, be compared and, indeed, can almost be predicted; but for any particular season it is impossible to say how a manure is going to act. Farming for one year only is so speculative that no one could engage in it; only when the farmer is able to continue for a number of years so as to include good seasons with bad ones can he use manures with certainty of advantage to the farm and himself.

A further complication arises from the fact that manures are not single substances. The plant, for instance, requires Nitrate-Nitrogen for its growth. But it is chemically impossible to supply Nitrate-Nitrogen alone; it must be given in combination with something else. Now this other component may have no effect, or it may be harmful or beneficial, but whether the farmer wants it or not it must be there. In the case of Nitrate it so happens that the things most convenient to the fertiliser manufacturer are also of value to the farmer; the Soda in Nitrate of Soda and the Lime in Nitrate of Lime are both useful to the plant and in the soil. But this does not always happen. The Sulphate in Sulphate of Ammonia is in some cases directly harmful, and counteracts part of the good done by the Ammonium, which is the really valuable fertiliser constituent. Yet there is no way of doing without it, and the substitution of some other compound is with few exceptions no improvement from the agricultural point of view. The exceptions are Ammonium Nitrate—theoretically almost a perfect manurial substance—and Ammonium Phosphate—theoretically nearly perfect; yet in both cases there is some practical disadvantage or inconvenience, so that from the working farmers' point of view they are not as superior to the ordinary Sulphate of Ammonia as might be expected.

Six Groups of Manures.

The ingenuity of the agricultural chemist has provided the farmer with a large number of manurial substances, but they all fall into six groups, as follows:—

I.—Nitrogenous manures, supplying Nitrogen, the most important element for encouraging growth. Nitrate of Soda, Nitrate of Lime, and Nitrate of Ammonia (no longer available in this country, though still used on the Continent).

II.—Phosphatic manures, supplying Phosphate, highly important for root development, ripening of cereals, and for grazing land. Superphosphate, basic slag, bones in various forms, steamed bone flour, mineral phosphates, phosphatic guanos.

III.—Potassic fertilisers, supplying Potash, essential for sugar or starch-producing crops, for leguminous crops, and for thin, chalky, or sandy soils. Sulphate of Potash, Muriate of Potash, Kainit, Sylvinite, various minerals used on the Continent (e.g., Leucite in Italy), but not here.

IV.—Organic matter, highly important for improving the soil and benefiting the crop, and always supplying one or more of the above fertiliser constituents. Supplying Nitrogen only:—Shoddy, hoof and horn, fur waste, and feathers. Supplying Nitrogen and more or less Phosphate and Potash also:—Guano, fish meal, meat meal, dried blood, rape cake and like substances; castor meal, etc., farmyard manure, sewage sludge, seaweed, green manure.

V.—Lime, calcium oxide, or carbonate, essential for avoiding acidity or sourness in soil and for keeping the soil in really good condition for fertility. Lime in various forms:—Quicklime, burnt lime, cob lime, lime ashes, etc. Hydrate of lime. Carbonate of lime in various forms (chalk, limestone), various wastes, such as lime mud, Chance mud, etc.

VI.—Mixed manures, containing some of the above, mixed in such a way as to supply the needs of crops on particular soils or in particular conditions. Many proprietary articles.

Other Processes and Combinations.

It will readily be admitted that the list is long enough and sufficiently complex as it stands, but claims are sometimes made for other things right outside it. Thus it has been stated that radium and electricity both

confer special properties on manures, causing great increases in effectiveness, for which it is hardly necessary to say the farmer is invited to pay. There is no evidence in favour of these claims, and farmers purchasing such manures should regard the transaction as a speculation which may not come off.

Going back to the legitimate list of manures it must be emphasised that the first five classes are always needed somewhere in the rotation, and only in exceptional circumstances can the farmer safely omit any one of them. No permanent system of agriculture can be founded on omissions, though, perhaps, for a time, no disadvantage may be evident. It would be uneconomical to use farmyard manure alone, even if it were possible to obtain enough; it is difficult to use artificials alone, even when classes 1, 2, 3, and 5 are regularly and properly supplied, and still more so when any one is omitted.

Fig. 23.—The old way of making farmyard manure in Norfolk. Very effective, but it needs careful watching, or it becomes too costly.

CHAPTER X.

FARMYARD MANURE: MAKING AND STORING.

The making of farmyard manure is one of the oldest arts practised by agriculturists, but even to-day no one can fully explain the changes going on or can say with certainty how it should be done. For many years little advance was possible because of the expense of the work. Farmers everywhere owe a debt of gratitude to Viscount Elveden, of Pyrford Court, Woking, who for the past eight years has enabled Rothamsted to overcome this difficulty and maintain a trained chemist solely for the purpose of experimenting with farmyard manure and trying to find the best ways of making, storing, and using this valuable fertiliser.

The best practice is to let the animals tread the litter in a covered yard or box, using sufficient litter to absorb all the liquid excrements. Excellent manure can be made in this way, but there is always a loss of about 15 per cent. of the nitrogen, even under the best conditions, and no way of avoiding this trouble has yet been discovered. It is usual for the farmer to rely entirely on his judgment in deciding how much straw to use, but modern investigation shows that the best results are obtained when there is a definite proportion between the amounts of straw and of albuminoids in the food. It is found that 1 ton of straw should go to every 100 lb. of digestible albuminoids in the ration; if more straw is used, the manure does not make well, and if less, then some of the nitrogen is lost. It is also found that the urine of the animals, especially when they are on a rich diet, is too strong to give the best results, and that improvements can be effected if water is added. These ideal conditions have not yet been attained in practice, and they are mentioned only to show that there are still improvements possible even

in so ancient an art as the making of farmyard manure.

Many farmers have insufficient covered yard space, and are compelled to make some of their manure out-of-doors. In this case losses are bound to be severe; they can, however, be reduced by adding more litter—if straw is short, bracken can be used. But whenever there are pools lying about, or streams of black liquid draining away, the farmer may be sure that losses are going on; and, unfortunately, it is always the best that goes first, and the poorest that remains.

In the old days farmers used to turn their manure before applying it. The practice has something to recommend it on dry, sandy soils, but it is very expensive, and involves much loss of valuable ammonia. A better way, as will be shown later on, is to plough in the manure in early winter, so that the "making" can finish in the soil, where it goes on with much less loss than in the air.

The Storing of Farmyard Manure.

This is quite as important as making, and many a lot of good manure has suffered considerably in value by bad storage. In fairly dry conditions the manure is best worked into the soil in autumn and early winter, but this means that the winter's make of manure has to be stored somehow through the summer, the worst period in which to keep it. The best method of storage is to keep the manure compact and sufficiently moist. Where the yards are covered it can probably remain there better than anywhere else; this is often practicable in Norfolk, and, while it has faults, no better plan has been worked out. It would be useful to try clamping part of the manure and comparing it with the rest that had lain undisturbed. Of course, if pigs or other animals remain in the yard the manure is better left as it is; it will suffer less by staying there than by being moved.

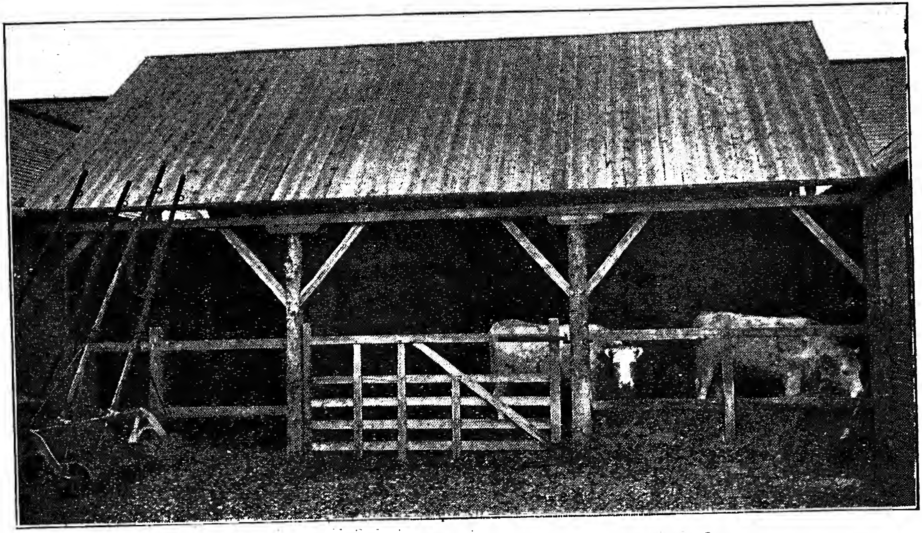


Fig. 24.—Covered yard. A good way of making farmyard manure.

Where the yards are open the manure should be hauled out before the warm weather begins. The two great enemies of farmyard manure are sun and heavy rain, and in an open yard it is liable to get both. The manure should therefore be hauled out and made into a mixen in the spot most convenient for the winter carting, and then given some shelter. It has been proved over and over again that even a small amount of protection is beneficial — a layer of earth, a few broken hurdles thatched with straw, the shade of a tree, have kept off the sun's rays and given sufficient protection to save the heap from much loss. In the Rothamsted experiments the sheltered manure gave 1¼ tons more potatoes per acre than the unsheltered; in the Glasgow trials and those made by Mr. Bradshaw in Co. Armagh, there was also a distinct gain.

Are Fixers any Use?

Farmers are periodically advised to add certain things to their manure heaps with the idea of "fixing" the ammonia and reducing loss. Gypsum used to be widely recommended, but sometimes kainit or superphosphate was suggested instead. There is no evidence that any of these is any good, and it is much better to trust to proved remedies such as shelter and compacting; a layer of earth put on the top gives an even better result.

Heavy Cake Feeding.

In the palmy days of agriculture sixty years ago, when profits were more easily made at farming than now, farmers felt justified in fattening bullocks for the sake of the dung. Most excellent manure was produced. The tradition still remains that cake "fats the cattle, fats the land, and fats the farmer," and it is still true that cake-fed dung is a very valuable fertiliser and much better than dung made without it. But it is

equally true that nowadays *it does not pay* to give heavy rations of cake. Farmers are being compelled to revise their rations and to alter their methods of beef production. The new methods do not give as good manure as the old, but that cannot be helped. There is the consolation that the superiority of heavy cake-fed dung does not last long, and that in many cases the same effect can be obtained by more ordinary dung made with more profitable rations of cake, when this dung is used with artificials as shown later.

Dairy Manure.

This presents a much more serious problem since the manure must be cleared out daily in order to keep the cowsheds clean, and it must be stored somewhere so that it can be used when convenient. The worst plan of all is that adopted in some of the northern hill farms, where the manure is simply thrown out from the byre through a hole in the wall and is then left exposed to rain, wind, and sun till its goodness must have nearly vanished (Fig. 25). The best plan at present practised is to store it in a dungstead, running a cart over it so as to keep it compact. Fig. 26 shows a good type; it is provided with a sloping floor so as to increase its capacity, and it has a tank into which the liquid can drain and then be pumped on to the manure as it is carted to the field. A sheltered place of this kind gives useful provision for the solid part of the manure. Obviously, however, no elaborate arrangement is desirable; it would be futile to spend more on the dungstead than the saving would be worth.

Liquid Manure.

On a dairy farm, however, there is a good deal of liquid manure arising from the animal excretions, the washing of the cowsheds, etc. Analysis shows that 1,000 gallons (4½ tons) of the liquid contains about:—

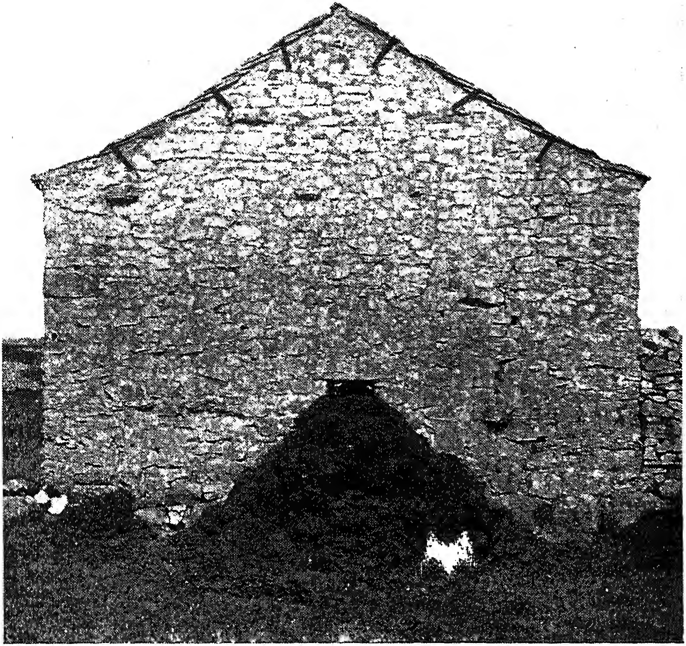


Fig. 25.—Worst way of storing dairy manure. It is simply thrown through a hole in the wall, and left exposed to sun and rain.

20½ lb. nitrogen, equal to that present in 100 lb. sulphate of ammonia; 3 lb. phosphoric acid, equal to that present in 25 lb. superphosphate; 46 lb. potash, equal to that present in 3 cwt. kainit.

Every farmer knows that this material should not be wasted, but should be run into a liquid manure tank. Unfortunately there is a big gap between knowledge and practice, for on many farms tanks do not exist, and on those which are fortunate enough to possess them they are often not used. And yet a dressing of 1,500 gallons to the acre has a remarkable effect on leys or on grass laid in for hay; if a man has enough he can use it on oats with advantage. It is valuable both for its nitrogen and its potash.

There is sometimes the possiblity of buying a suitable cart fairly cheaply from city or town councils who are changing from horse-drawn water carts to motor carts. Where the farm is on sloping ground such a cart forms the most convenient tank, for it can easily be emptied and cleaned out.

The Question of Litter.

Three materials are commonly used for bedding—straw, peat moss, and bracken. From most points of view straw is the best; it is a home product, and therefore needs only a minimum of carting; it contains substances needed on the farm, and it is usually available without spending money. Peat moss absorbs the liquid excretions better, but there is nothing to show that it is finally as good as straw. Bracken is quite useful where it can be cheaply cut and carried.

CHAPTER XI.

FARMYARD MANURE: WHAT IT DOES AND HOW TO USE IT.

No one completely knows all that farmyard manure does. It increases crop growth, but so do artificial manures; yet farmyard manure does something which these do not. When used regularly it gives a steadier yield than is possible with artificials; in a good season, it is true, the crops may not be as high, but in a bad season they do not fall as low—while farmyard manure will not make fortunes, it will not let a man down. Further, farmyard manure much benefits the clover crop, and thus increases the productiveness of the farm. And, lastly, farmyard manure maintains the fertility of the soil; one can adopt a most exhaustive system of husbandry and keep it up indefinitely so long as farmyard manure is used—though other things, such as lime, slag, etc., may be necessary, and in the case of grazing land may even be better (Fig. 27).

How is it done? What are the constituents of farmyard manure that confer these valuable properties? In spite of years of work we do not fully know. The chief constituents are, of course, well ascertained: they are nitrogen, potash, phosphates; a 10-ton dressing of dung contains about as much of these as would be supplied by 6 cwt. nitrate of soda, 4 cwt. super-phosphate, and 2½ cwt. sulphate of potash. But these alone do not account for everything. They afford no explanation of the remarkable effect produced by farmyard manure on soil tilth, which shows itself in an increased power of holding water—invaluable in a dry season—and also in the case with which a tilth can be obtained, which is of special importance to the root crop.

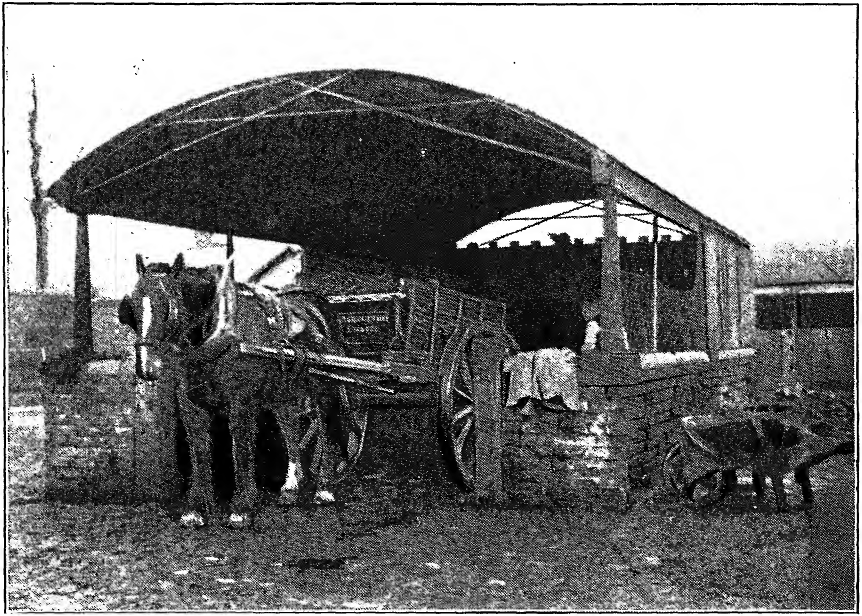


Fig. 26 —Much better way of storing dairy manure. A roof is fixed over the heap, which is so arranged that the dung-cart can be backed on to it to keep it compact.

For what Crops should Farmyard Manure be used —and when?

This depends very much on the purpose the manure has to serve. If the soil is liable to dry out, as on light soils in Norfolk, Suffolk, Bedfordshire, and the Eastern and Southern parts of England, then the farmyard manure is best applied to the root crop, so as to ensure a good development of the young plant. Otherwise it would go on the most valuable crop, whatever it might be, this being the one where its steadying effects on yield will be most useful. There are special cases, however, where it is best used on grass, as on some of the Wiltshire dairy farms, the arable crops being grown on artificials fortified by sheep folding.

The general rule as to time of application is that in very wet districts farmyard manure is best applied in spring, while in drier districts it is best ploughed in

Wet District: Spring Application Best.
(West of Scotland.)

	Potatoes. Increase over unmanured plot.							Turnips. Increase over unmanured plot.						
	Weight per acre.		Moneyvalue per acre.			Per cent.		Weight per acre.		Moneyvalue per acre.			Per Cent.	
	Tons.	Cwt.	£	s.	d.			Tons.	Cwt.	£	s.	d.		
Spring application	4	2	9	3	2	57		6	2	2	8	6	41	
Autumn application	2	1	4	12	0	26		3	14	1	9	6	25	
Advantage of spring dressing	2	1	4	11	2	31		2	8	0	19	0	16	

Drier District: Autumn or Early Winter Application Best.
(Holmes Chapel, Cheshire.)

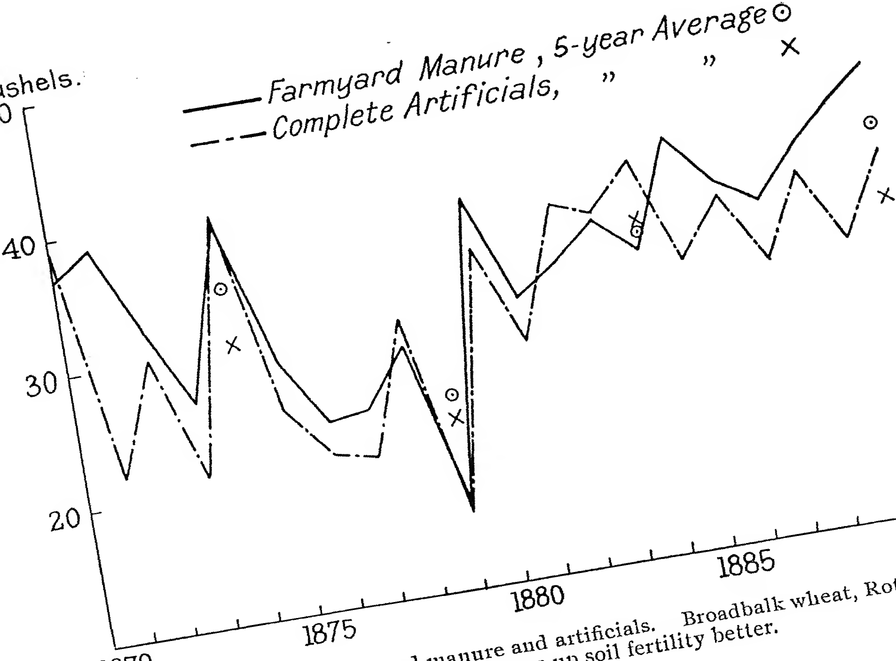
	Potatoes.	Swedes.	Mangolds.
Dung applied in December ..	5.7	14.5	22.1 tons per acre
,, ,, April ..	5.5	12.8	17.7 tons per acre
Advantage of winter dressing	—	1.7	4.4 tons per acre

in autumn. Thus definite experiments have shown the superiority of spring applications in the west of Scotland and of autumn applications in the eastern part of England and the dry strip in Shropshire and Cheshire. Some of the results are shown in tables on page 73.

It is not always economical, however, to use the manure at the time when it would be most effective: storage involves loss, and it may prove better to use it as soon as it is made rather than to hold it in the hope of obtaining more benefit later on. A light-land farmer may do better to use his manure in March for mangolds and in April or May for turnips, than to keep it till the following autumn when he might get better results per ton of manure, but at a greater cost through loss in storage than he would gain. A heavy-land farmer could hardly apply the manure so late to his roots, but might with advantage give to the clover such as was ready in February: the manure made afterwards, however, would have to be stored till autumn.

How much to Use and with what Help.

The great question of how much farmyard manure to use need not detain us, since it usually has to be spread over as wide an area as possible. It is some consolation to know that large dressings are wasteful, giving smaller profit than less heavy applications; but whether the dressing be small or large it should be applied evenly. Many farmers put on the dung by sheer guesswork, and it must be admitted that a skilled hand can do it very well. Unfortunately all labourers are not particularly skilful and some guidance is desirable; in the Lothians an excellent marker is used which goes over the field, marking it into squares of 6 yards wide, of which 134 go to the acre; the machine is called a "Dumb Tam" from its originator. Into each square is dumped 2-2½ cwt. of the dung; thus one cart does six to eight squares; the dung can then be



f farmyard manure and artificials. Broadbalk wheat, Rot
ure keeps up soil fertility better.

spread very evenly. Having spread the dung it should be ploughed in as quickly as possible. There has been much discussion on this point: some have considered that the dung could lie on the ground for a considerable time without fear of loss, while others consider that it is much injured by frost. It is not easy to see how this last can happen, but there is no doubt that the dung is safest under the ground, where it does much more good than lying on the top.

Farmyard manure should generally be used with artificials. There is much evidence to show that better results are, as a rule, obtained by the two kinds of fertilisers together than by either separately (Fig. 28). The exception is the swede crop, which often (though not always) gives no better yield for dung+artificials than for dung alone; this is specially true of districts where the crops do not generally exceed 14 or 15 tons to the acre. Thus at Rothamsted swedes gave the following yields in tons per acre:—

No manure.	10 tons dung.	10 tons dung + artificials.	Artificials alone
9.6	12.9	12.9	12.7

But for potatoes, mangolds, cabbage, kale and rape it is better to use artificials and a moderate dressing of dung (say 10 tons to the acre) than to use more dung and no artificials. Not only are the yields heavier, but the crops are healthier; they resist disease attacks better, and they are usually of better quality. Thus, on the mangold plots at Rothamsted, farmyard manure alone gives quite a fair crop, but the addition of artificials results in an extra 8-10 tons per acre, besides improving the quality.

Even for the swede or turnip crop it may be better to add the artificials if a yield of over 20 tons can reasonably be expected. Thus for turnips the following results were obtained by Hendrick and Greig

at Aberdeen in a favourable season in which the manures were able to exert their full effect:—

Dressing per acre	10 tons dung	10 tons dung + 1 dose of artificials.	10 tons dung + 2 doses of artificials.
	Tons. Cwt.	Tons. Cwt.	Tons. Cwt.
Yield of Turnips	17 10¼	20 15½	22 12

Much more evidence might be brought to show that it is *better economy to use moderate dressings of dung, and to supplement them with artificials, than to use large dressings of dung without artificials.* We shall discuss later on the best kind of artificials for various crops.

Use of Farmyard Manure on Grassland.

As already stated, some farmers find it advantageous to use their farmyard manure on the grassland. This practice is better for hay than for grazing. On the Rothamsted plots farmyard manure applied once in every four years gives a satisfactory crop, though here better results are obtained when something is given in between whiles. Thus when dung is put on every fourth year, with fish guano two years after, the crops often run up to 2½ or 3 tons of hay per acre, and the quality is not too coarse. The crop is much larger than where artificials only are given, but it is doubtful whether the net result is much better, as the amount of clover is considerably less. Still, for a dairy farmer a good bulk of hay of reasonable quality is very well worth striving for. Similarly, when artificials are applied two years after the dung, a better result is obtained than when the dung is used alone.

It is less satisfactory, however, to use farmyard manure on grazing land, and this course should not be adopted unless there is very strong reason to know that it is the best in the circumstances.

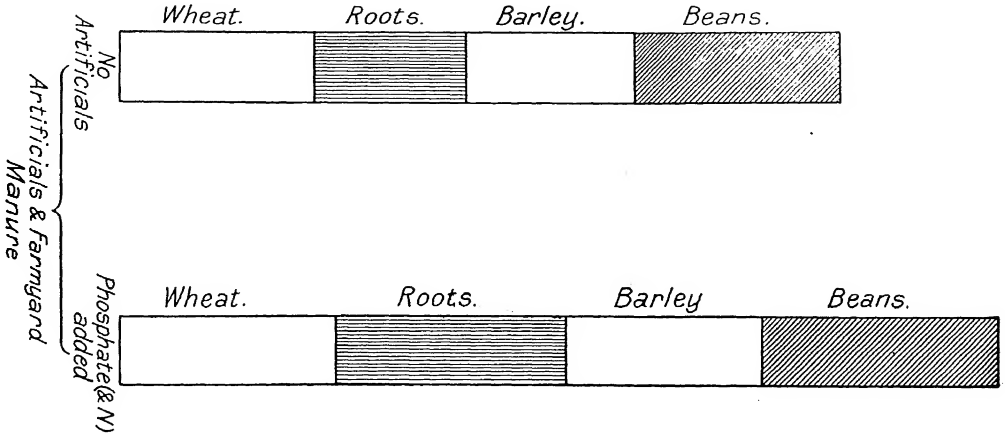


Fig. 28 —Saxmundham experiments, showing the value of using artificials along with farmyard manures. Yields are indicated by height of columns.

CHAPTER XII.

THE NITROGENOUS FERTILISERS.

NITRATE OF SODA AND SULPHATE OF AMMONIA.

Few fertilisers give more striking results than these two nitrogenous manures when properly used, or prove so ineffective when wrongly applied. In the case of most of the fertilisers to be described later, a farmer who makes a mistake or secures no profit in his first season has a very good chance of coming out right in a later season, since any material which has not benefited the first crop remains in the soil and may benefit a second or third crop. But in the case of the nitrogen fertilisers there is, as a rule, no second chance, and any profit that fails to appear in the first season must be given up as hopeless; it may by a stroke of luck turn up in a second year, but the chances are remote. It matters little whether the failure in the first season is a man's fault or his misfortune; these valuable fertilisers are by no means foolproof, and in certain conditions do not act well. But a man who knows something about them is not likely to go wrong, and few aspects of fertiliser practice better repay study than the proper use of these substances. Here, for example, is a table drawn up from practical measurements on farms showing the sort of return that can reasonably be expected from the application of 1 cwt. nitrate of soda or sulphate of ammonia per acre :—

		Per 1 cwt. of sulphate ot ammonia or nttrate of soda
Wheat,	grain	4½ bushels.
,,	straw	5 cwt.
Barley,	grain	6½ bushels.
,,	straw	6¼ cwt.
Oats,	grain	7 bushels.
,,	straw	6 cwt.
Hay		8-10 cwt.
Mangolds		32 ,,
Swedes		20 ,,
Potatoes		20 ,,

No other fertilisers give results of this kind.

Nitrate of Soda.

This is the quickest acting manure in general use, and under favourable conditions it shows its effects in two or three days. It gives a more vivid green to the leaves and causes more rapid growth, so that it often causes plants which have stood still during a spell of cold weather to start growing again. This is a very great advantage in case of attacks by insects, which eat part of the plant, such, for instance, as wireworms, which damage the roots and stems, and certain insects that eat the young leaves; with more rapid growth the plant is able to replace the tissues as fast as they are destroyed, and thus to keep it alive until it is out of danger of further attacks.

The additional growth induced by nitrate of soda is of particular value for hay. When properly used this manure gives valuable increases in the bulk of hay without much lowering of quality. But there is, perhaps, no direction in which nitrate of soda is more frequently wrongly used. The ease with which extra hay can be obtained by the simple device of applying 1 cwt. fertiliser has led some farmers near to towns to give nothing but nitrate of soda year after year to their land. This was quite a common practice in the meadows north of London, and for a time it was profitable; but it is not a fair way of using nitrate of soda, and it was responsible for giving this fertiliser the name of a scourge or a stimulant only, which it does not deserve. The Rothamsted grass plots, receiving nothing but nitrate of soda, gave at first a very fair crop, but deterioration set in, and now both yield and quality are reduced; the yield is on an average half a ton per acre less than it was, and weeds form more than half the herbage, while the valuable clovers have been crowded out. The proper course is to recognise that *plants cannot live on nitrogenous*

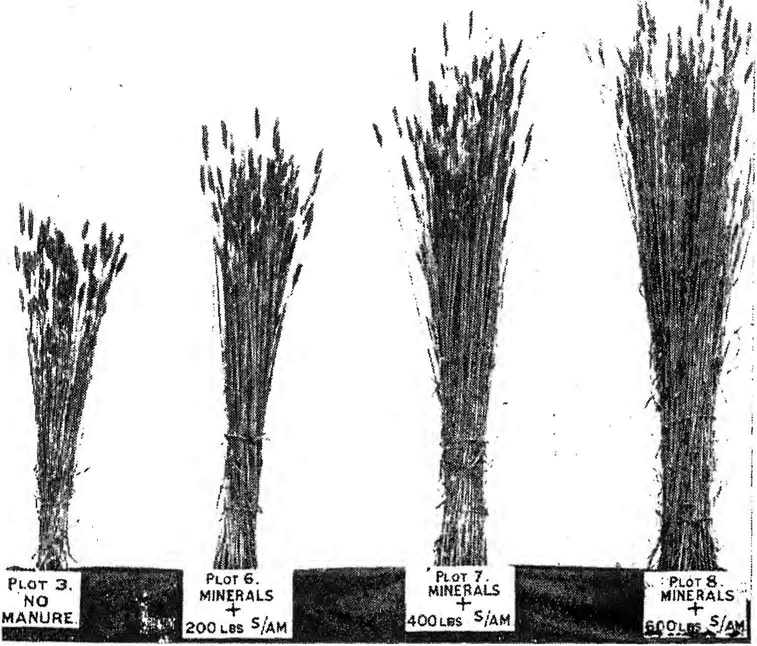


Fig. 29a.—Nitrogenous manures cause larger crops. Samples from Rothamsted plots showing (left) yield where no manure is given, and (centre and right) yield where fertiliser including nitrogenous manure is applied.

manures alone, but require also potash and phosphate. When the complete manure is given, the yield of hay is better and the quality is maintained for a longer period. On the Rothamsted plots the results are:—

	Cwt. hay per acre, less 10 years average	Quality
Wrong manure:—nitrate of soda only	$25\frac{3}{4}$ cwt.	Much weed
Right manures:—nitrate of soda + superphosphate and potash	40 cwt.	Less weed, more clover

Another crop very responsive to nitrate of soda is the mangold. This crop is capable of more growth than any other on the farm; it may give yields of anything from 25 to 90 tons per acre according to its treatment. Many dairy farmers treat their crops very liberally with dung, but even so it is always worth trying whether additional yields cannot be obtained by giving some nitrate of soda as well. This always happens at Rothamsted; even where 10 tons of dung are supplied to the crop on land that has been liberally manured in the past, a top-dressing of nitrate of soda gives an extra 8 tons per acre of mangolds. Again, however, it is desirable to supply some superphosphate and potash, and in the case of this crop salt also.

Cabbages furnish a good example of what nitrate of soda can do on a leafy crop. They are generally pretty well treated, but it is useful to remember that a dressing of nitrate of soda applied in the early days gives a good start, while a dressing towards the end gives a fresh green colour which much improves the appearance of the crop when it is cut. It also makes the leaves more tender, an advantage when the crop is being sold locally, but a disadvantage when it has to be sent long distances by rail or subjected to rough handling.

Nitrate of soda should be used with caution on heavy arable soils, as it tends to poach them.

Sulphate of Ammonia.

This fertiliser is now well known to farmers, and has come into considerable prominence of recent years. It is not too much to say that sulphate of ammonia played a great part in helping to win the war, since it furnished the additional nitrogenous manure necessitated by the food production campaign, as well as helping to provide high explosives. Like nitrate of soda, it is by no means fool-proof; properly handled it gives excellent results, while if wrongly used it may be wasted, or even in some cases do harm.

The right way to use sulphate of ammonia is to apply it at or before the time of seeding to roots, barley, spring oats, and potatoes, and to give as a top-dressing for winter corn. The wrong way is to use it on land deficient in lime especially if carrying a corn crop in which clover seeds are sown, either pure or mixed with grass. On such soils lime ought always to be applied before this fertiliser is used.

Sulphate of ammonia is not as quick in action as nitrate of soda, but on the other hand it does not as readily wash out of the soil, and this gives it a considerable advantage in regions of high rainfall, such as the lighter soils in wet parts of our own country, and more especially in sub-tropical countries, in Japan, and elsewhere.

Finally, it is safer than nitrate of soda on heavy soils, since it has no tendency to poach the land; but, on the contrary, rather improves the tilth.

Excellent results are obtained by using it on potatoes, and many good potato fertilisers are made by mixing sulphate of ammonia, superphosphate, and sulphate of potash—about 1½-2½ cwt. per acre sulphate of ammonia, 4 cwt. superphosphate, 1-1½ sulphate of potash per acre, being quite a useful dressing. Experiments all over the country could be quoted to show the advantage of sulphate of ammonia for this crop.

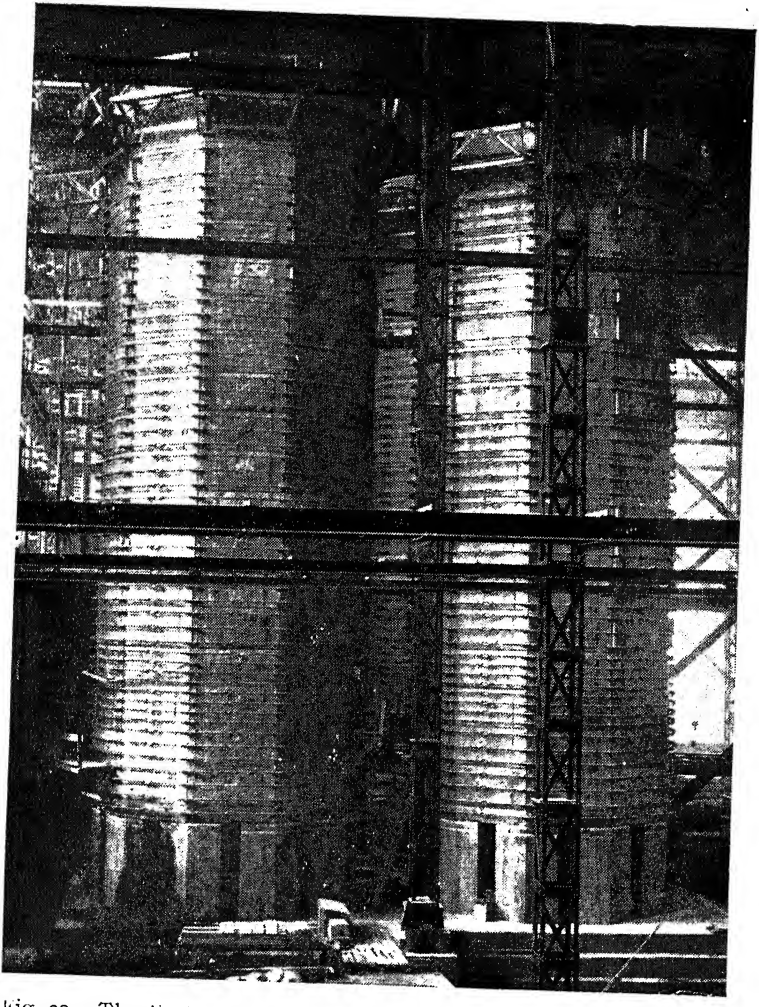


Fig. 29.—The Factory. The new fertilisers being made. One of the processes in which the nitrogen of the air is converted into a valuable fertiliser.

As a spring dressing for winter corn $\frac{3}{4}$ to $1\frac{1}{2}$ cwt. per acre has proved quite useful. Many farmers use soot, and with excellent results, but soot owes its manurial value to the fact that it contains sulphate of ammonia. Two points about top-dressings ought to be remembered. Winter rain washes out nitrates from the soil and leaves the crop without its necessary nitrogenous food supplies. Whenever, therefore, the winter has been wetter than usual, it may be taken for certain that the crop will need a nitrogenous manure as top-dressing in spring. The second point is in regard to the quantity to use. This, of course, must depend on the value of the crop and the cost of the manure, but there is evidence that a bold policy may lead to larger crops, and, at reasonable prices, to larger profits.

The New Nitrogen Fertilisers: Will They Help the Farmer?

The new nitrogen fertilisers were brought into being through the fear of food shortage and greatly developed by the war. Some thirty years ago Sir William Crookes showed that the supplies of nitrogenous fertiliser then in sight were insufficient to meet the growing demands of the world, and that unless something were done the world would be faced with a shortage of food soon after 1930. Chemists immediately set themselves to prepare the necessary fertilisers from the inexhaustible supplies of nitrogen in the air, and processes were soon at work in Norway and Sweden; later on, a greatly improved method was started in Germany, and early in 1914 the problem seemed to be completely solved. Unfortunately, the nitrogen compounds thus made were readily converted into high explosives, and as soon as the German factories were well at work the war broke out. The need for explosives was so great that other countries took up

the manufacture of nitrogen compounds, and now (after the war) it is possible to prepare any desired quantity in the form of valuable fertilisers. Fear of nitrogen starvation has therefore vanished.

NITRATE OF LIME.

The farmer is now offered a choice of these fertilisers. One of the first to be made was nitrate of lime, which was sent over from Norway. It has now been carefully tested at a number of centres with quite satisfactory results. It is much like nitrate of soda, is rapid in action, so that it readily spreads about in the soil and quickly reaches the plant roots. In consequence it is very easily taken up by plants, it speedily improves their colour and appearance, and induces quick growth. It suffers, however, from the drawback inherent in very soluble nitrogen fertilisers, being liable to wash out of the soil after heavy rain. The way round this difficulty is to use it as a top-dressing, preferably in showery weather, so that the plant shall have abundant opportunity of taking it all up.

In all these respects it resembles nitrate of soda, but there are two ways in which it differs—it contains no sodium, and therefore is not quite as good for mangolds; and it does not cause heavy soils to poach. A number of experiments have been made comparing nitrate of soda with nitrate of lime; sometimes one has come out best and sometimes the other, but on the balance there is very little to choose between them. Excellent results have been obtained with mangolds and hay, and, as a top-dressing, with wheat. The lime present is an advantage on soils deficient in this substance.

There is a difference in the amount of nitrogen in these two substances, so that a direct comparison in price is not easy. As a rule, nitrate of soda contains

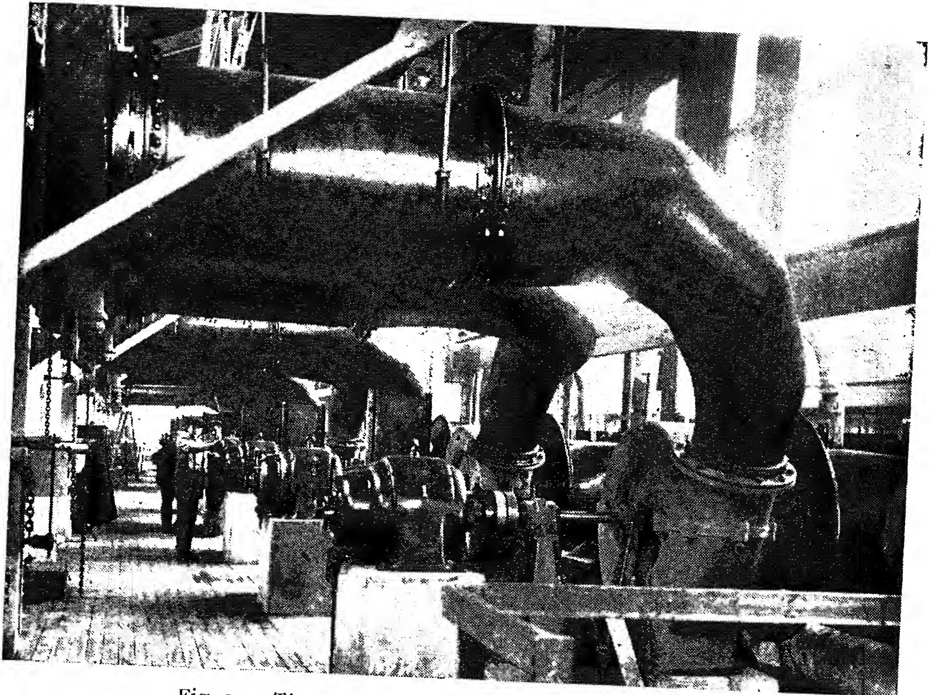


Fig. 30.—The Factory. Another process illustrated.

15½ per cent. nitrogen, and nitrate of lime about 13 per cent. 1 to 2 cwt. per acre is a suitable quantity: it should be used in spring.

Muriate of Ammonia.

One of the most important new fertilisers is ammonium chloride, or muriate of ammonia, which can readily and cheaply be made in very large quantities. It contains rather more nitrogen than the sulphate. It has not been obtainable for a sufficient length of time to enable complete tests to be made, but up to the present the indications are that it is nearly as good as sulphate of ammonia in normal moist conditions, though it appears to be less good in very dry conditions.

The Newest Fertiliser: Urea.

The newest of all these fertilisers is urea. Tests show that it is practically as good as sulphate of ammonia or nitrate of soda, and, in addition, is very highly concentrated, so that freightage and transport charges are all reduced to a minimum. It contains no less than 47 per cent. nitrogen, and is thus more than 2¼ times as concentrated as sulphate of ammonia and 3 times as concentrated as nitrate of soda. Wherever transport and cartage are a consideration this is a great advantage. From experience hitherto gained it does not appear to give its best results when used as a top-dressing, and is better applied at the same time as the seed and put into the soil, so that it can be speedily covered up. It seems to be safe for all crops, and does not make the soil acid, nor does it cause poaching of heavy soils; indeed, it appears to be remarkably free from any indirect action on soil such as other fertilisers show.

The net result of all this activity on the part of chemists and engineers is that the farmer is now put in possession of several new fertilisers, each of which has something to recommend it either on the score of

economy or of specal effectiveness in certain conditions. It is too early yet to dogmatise about these manures; experts in different parts of the country are carefully studying them, and obtaining information that will enable us to say definitely just what are the advantages and disadvantages of each of these new compounds.

CHAPTER XIII.

THE PHOSPHATIC MANURES.

Superphosphate.

Superphosphate was one of the first artificial fertilisers to be placed on the market, the process of manufacture having been invented by the late Sir John Lawes in 1843; it is, therefore, eighty years old. It still retains its popularity amongst farmers, and is widely used by them and also by manufacturers of compound manures. With the exception of dissolved bones it is the only fertiliser containing water soluble phosphate.

The other phosphatic manures that have been produced since superphosphate was brought into notice include basic slag and mineral phosphates, but in reality there is frequently no great competition between them—especially between slag and superphosphate—owing to the fact that each has special properties that confer on it a special value. Superphosphate is pre-eminently the phosphatic fertiliser for arable land, especially in dry conditions such as prevail throughout the whole of the eastern part of England. In the wetter conditions of the west and the warmer conditions of the south-west, basic slag is as effective on certain crops, but not on all; but wherever the rainfall is less than 26 inches per annum the farmer must rely chiefly on super to supply phosphates for his arable land. On grass land the tale is different.

Potatoes and Swedes need Superphosphate.

For the potato crop superphosphate can be used under any conditions of soil or rainfall. In the Fens farmers use little else; on loams and sandy soils they must give potash, sulphate of ammonia, and farmyard manure in addition; but whether potatoes are grown in the north, south, east, or west, they require superphosphate to yield the best results.

The quantities per acre depend on the size of the crop

that can be obtained, the general rule being that a heavy crop requires a larger dressing than a small one; usually about 4 cwt. per acre makes a satisfactory dressing, with 1 cwt. of sulphate of ammonia and 1 cwt. sulphate of potash in addition to dung. In some districts, however, more is recommended; in Lancashire 6 cwt. of super with 2½ cwt. sulphate of ammonia and 2 cwt. muriate of potash has been advised. In the south-west of Scotland and the Northumberland and Durham districts it has been recommended that some of the superphosphate should be replaced by basic slag, a mixture of 3 cwt. of each having been found quite useful. On a good Fen soil where heavy crops can be obtained farmers have used as much as 8 cwt. per acre super with advantage.

Trial should always be made of the best quantity: no analyst can give much help here, and there are cases where too much is being used, and the crop is being reduced in consequence.

Another crop very responsive to superphosphate is swedes. Here again the quantity to be used depends on the size of the crop obtainable, and is higher for a yield of 25 tons per acre than for the smaller crops more prevalent in the south. If the climate allows only 15 to 20 tons of swedes per acre, it is obviously inadvisable to spend too much on manure; indeed, it may happen that nothing beyond a dressing of farmyard manure is wanted to give the necessary size of crop, although 2½ to 3 cwt. superphosphate may be expected to improve the feeding quality. In the north, however, where heavier crops are obtained, more liberal expenditure is justified and the dressing of superphosphate can be well increased to 4 or even 6 cwt. per acre.

Advantages of Basic Slag.

There are, however, conditions under which basic slag is better for swedes than superphosphate.

Fig. 31.—One of Mr. J. C. Brown's cabbage crops grown for soiling purposes at the Harper Adams Agricultural College, Salop. This method constitutes an improvement on the old root-break.

Wherever finger-and-toe is prevalent it is safer to use slag, and if the growing season is long and the climate moist (as, for instance, in the south-west of England and parts of the north), slag may prove as effective as superphosphate, and in some seasons it is cheaper. Slag comes slower into action, as a rule, than super phosphate, and would not always bring turnips on to hoe quite as quickly.

Where scab is common basic slag should not be used for potatoes.

Cereals.

A third crop responding very much to superphosphate is barley. It has been shown that barley taken after roots which have been fed on the land is improved in quality and in strength of straw by a moderate dressing of superphosphate. There is a further effect of great value not only in this crop, but in certain cases in others also. Superphosphate hastens ripening of grain and consequently can be used with advantage wherever earliness is desired. A good example was obtained in a high moorland district in the west, where oats ripened late and were harvested only with difficulty. This experience is familiar to hill farmers. It can be overcome in two ways, both of which could be adopted—by changing the variety for one more suitable to cold conditions, and by manuring with superphosphate. In the case under consideration the local variety of oats gave 27 bushels per acre and ripened late, so that there was much anxiety about the harvest. A dressing of superphosphate caused this same variety to yield over 45 bushels per acre, and to ripen earlier. One of the newer varieties, however, gave over 54 bushels per acre, and ripened earlier; it also stood up well. The same effect is produced on wheat, and wherever there is trouble about late ripening, it is always well to try and overcome it by giving 2 cwt. per acre of superphosphate.

Mangolds.

It is customary in some places to give rather large dressings of superphosphate to mangolds, but this practice requires careful testing, as it is by no means certain that any gain results. The advantage of a small quantity (2 cwt. per acre) of superphosphate is that it helps to bring on the mangold crop in the early stages and so encourages the plant to establish itself; but if too much superphosphate is given, it seems possible that the plant will hasten on its ripening processes, and this is not wanted in the case of mangolds. Farmers speak, of course, of mangolds being ripe, but they mean something quite different from the ripening of cereals. The mangold is really a biennial, and its natural function, as in the case of wheat and oats, is to produce seed; the ripening of mangolds would, therefore, correctly mean the ripening of the mangold seed. Now, that is not what the farmer wants. His object is to delay true ripening as much as possible, so as to secure a big production of root. Some of the Rothamsted experiments seem to show that large dressings of superphosphate are not helpful:—

Tons per Acre.

	1918	1919	1920
Large supplies of phosphate	28.6	13.0	26.1
Smaller supplies of phosphate	26.6	20.4	29.4

The experiment deserves careful repetition in other districts where mangold-growing is important.

Buying of Superphosphate.

The usual grades of superphosphate contain soluble phosphates which, when calculated as tri-calcic phosphate, are equal to 26 per cent., 30 per cent., and 35 per cent. of the total weight of the manure. Sometimes it is stated that superphosphate makes the soil acid, but this is not strictly correct.

Basic Slag.

This fertiliser has been available for farmers for some forty years, and has become increasingly popular. It is emphatically the fertiliser for grass land, though under certain conditions it serves a very useful purpose for arable land. The type of grass land that benefits most by the use of slag is heavy land covered with poor herbage containing large quantities of "bent grass," which goes brown in autumn, giving a brown, parched look to the herbage. Sometimes drainage is necessary, sometimes it is not; occasionally, as on some of the sourer soils of the North of England, lime must also be added; but slag has shown itself the best improver of pasture land in this country. Hay land has also benefited considerably from the use of slag, but more usually by improving the quality than by adding to the quantity. The great action of slag is to encourage wild white clover. These facts are well known to farmers.

Since the older agricultural experiments were made a change has occurred in the methods of making basic slag, and the material now obtainable is not generally as rich as that which was on the market before the war. In pre-war days there was no difficulty in obtaining a slag of 38 per cent. or 42 per cent. total phosphate, with a solubility of 85 per cent. by the official citric acid test. Nowadays this type of slag is not common, but a certain amount is still provided in this country, and some is imported from abroad. The slag ordinarily available now contains only about one-half as much phosphate as before the war, and until evidence to the contrary is forthcoming it must be assumed to have only half the value per ton of the former. It is necessary to bear this in mind to prevent disappointment.

Value of Slags.

Further, some of the slags, instead of having a solubility of 80 per cent., according to the official method, have a solubility of only 20 per cent. It would, however, be a mistake to suppose that they had only a quarter the value of the more soluble slags. The official method, in short, does not grade slags strictly in accordance with their agricultural value; it will, no doubt, be revised when further information is obtained. These new slags have not been under examination by experts for a sufficiently long time for us to know their exact agricultural value, but the evidence indicates that the new high soluble slags are probably as good as the old high grade pre-war slags when they are compared on equal phosphate content. The low soluble slags are quite effective, although they are slower to come into action than those of higher solubility. There are a number of experiments going on all over the country, the results of which will undoubtedly prove of value.

Usually the addition of slag brings on the wild white clover, and no one who has seen the Cockle Park experiments or those carried out in Essex by Professor Scott Robertson can fail to be impressed by the remarkable growth of this valuable plant (see Fig. 33). Even if there is no great visible change in the herbage there is often an improvement in the feeding quality which shows itself in a reduced cake bill.

Slag on Arable Land.

The use of basic slag on arable land is more specialised than that on grass land, since it is not always as effective as superphosphate. It cannot with certainty be used in the drier parts of England where the rainfall is less than some 25 inches per annum, and it is not particularly suitable for potatoes. In both these cases superphosphate is the safer substance, and is therefore

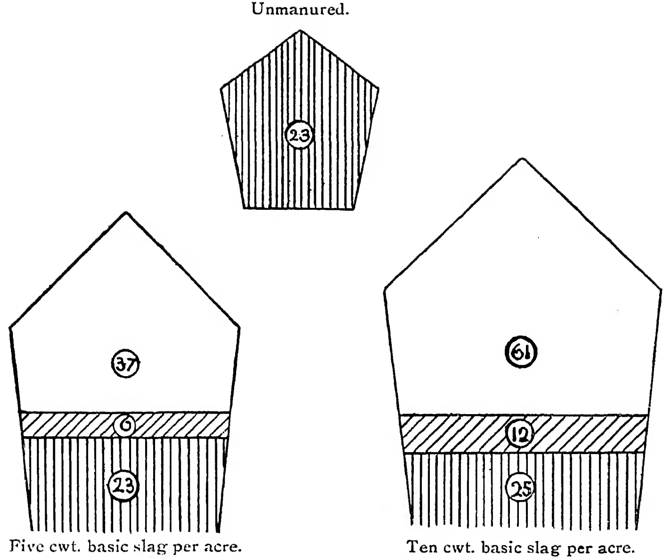


Fig. 32.—Effect of slag on grassland at Saxmundham. Lower part represents yield without manure; the centre portion what is required to pay for the cost of manure; and the top portion represents the profit.

more generally used. But wherever the land is inclined to be sour and to cause finger-and-toe in turnips, basic slag may with advantage be used. In the warm, moist districts of the South-West of England and in those parts of the North where there is a long growing season it can be applied to roots and also to the seeds ley, and may be expected to give as good returns as superphosphate, and it may be (though it is not always) cheaper. The high soluble slags are preferable for arable land.

Mineral Phosphates.

These are now beginning to appear on the market, and should be carefully watched by farmers. They gave quite promising results in the Essex grass land trials, and they are included in a number of the county manurial trials now being organised; they are being applied in Northumberland to barley in which clover is sown. It is too early yet to express an opinion as to their value, and it seems clear that very fine grinding will be necessary, the 120 mesh silver being better than the ordinary one of 100 meshes to the inch. From the evidence at hand, however, it seems that they will serve a distinctly useful purpose on the farm, and as they can be obtained in large quantities there should be no difficulty about supplies. On the present information the farmer should pay less for them per unit of phosphate than for slag.

How to Compare Prices of Slag and Superphosphate.

It is a simple matter to compare the prices of slag and of superphosphate. They are both sold on the basis of their phosphate content, and although the actual compounds are different in the two fertilisers, they are expressed in terms of the standard tri-calcic

phosphate. Thus, when superphosphate is described as "30 per cent. super," this does not mean that the superphosphate contains 30 per cent. phosphates, but that 100 lb. of it contains as much phosphatic material as is present in 30 lb. of the standard tri-calcic phosphate. So a 30 per cent. slag does not contain 30 per cent. phosphate, but, as before, as much phosphatic material in 100 lb. as does 30 lb. of the standard phosphate. If, therefore, 30 per cent. superphosphate is offered at £4 5s. each unit costs $\frac{85}{30}$ shillings = 2s. 10d., while if 20 per cent. slag is offered at £3, each unit costs $\frac{60}{20}$ shillings = 3s. Here the superphosphate is slightly the cheaper. This is given by way if illustration only, and does not represent the prices of any particular merchant. The prices should, of course, be worked out to include delivery at the farmer's station.

A Few Figures.

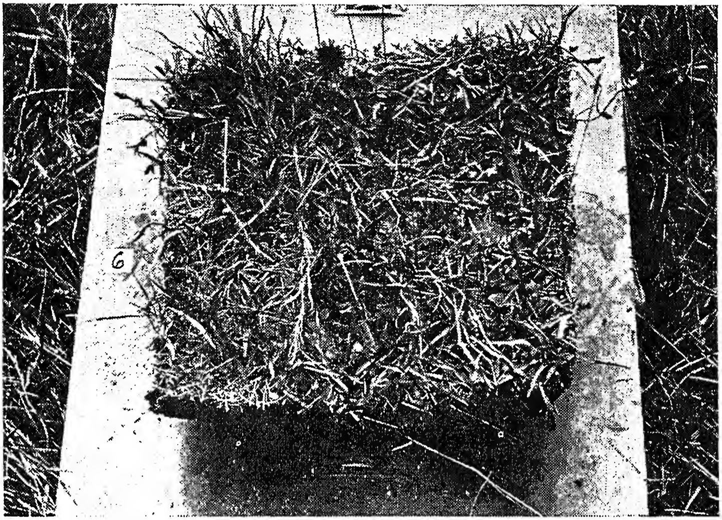
There is nothing so convincing as figures, and here are a few in regard to the effect of basic slag on grass land. They are taken from the Essex experiments, and are of special interest because the slags tested were of the type common nowadays, and they were not confined to the old high-grade Bessemer slag, which is now disappearing. In all cases the slags were applied in quantities to supply equal amounts of phosphate per acre. The increase in yield and the improvement in type of herbage should be noted.

Hay Experiment.

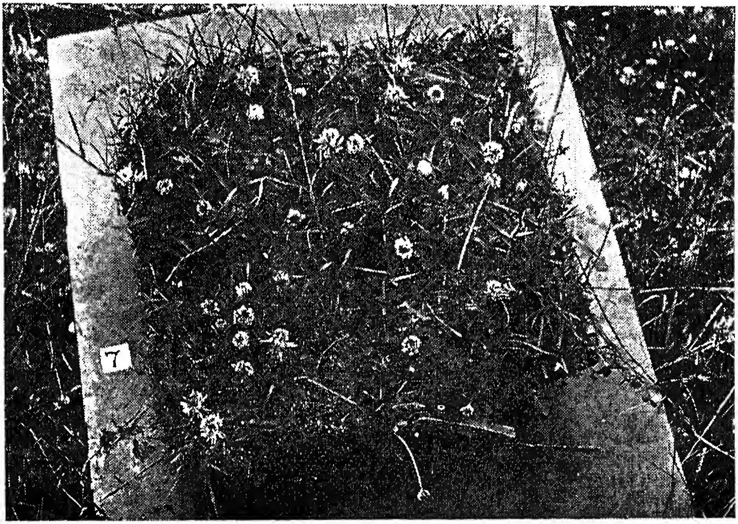
Saffron Walden: good soil.

Five Years' Average Yield, 1916-20.

	Yield of hay cwt. per acre
Bessemer Slag	40.9
Modern Slag, high soluble	39.2
,, low ,, ...	39.9
Mineral Phosphate	38.1
No Manure	30.4



6 No manure.



7. Basic slag.

Fig. 33.—The Results of Prof. Scott Robertson's experiments in Essex, showing how basic slag brings on white clover.

EFFECT ON VEGETATION.

Type of Vegetation	Farnham (Boulder Clay Soil) Plot 1 Openhearth Basic Slag (Solubility 20%)	Farnham Plot 2 High Citric Soluble Basic Slag (Solubility 91%)	Farnham Plot 3 No Manure	Horndon (London Clay) Plot 18 Openhearth Basic Slag (Solubility 20%)	Horndon Plot 17 High Citric Soluble Basic Slag (Solubility 91%)	Horndon Plot 16 No Manure
	%	%	%	%	%	%
Clovers ..	27.1	50.2	16.2	43.8	46.2	9.4
Grasses ..	45.0	33.3	18.4	31.8	47.2	19.1
Weeds ..	16.0	13.5	25.0	13.3	1.5	26.0
Bare space ..	11.9	3.0	40.4	11.1	5.2	45.5
	Manures sown February 22nd, 1917; Herbage analysed June, 1920			Manures sown February 27th, 1918; Herbage analysed June, 1920		

About 10 cwt. per acre is a suitable dressing for grass land as a first application, followed every fourth year by about 5 cwt. per acre.

CHAPTER XIV.

POTASSIC FERTILISERS.

The potassic fertilisers are the newest on the market, and did not become available in any quantity till some thirty years ago; they were thus fifty years later than superphosphate and the nitrogenous manures. But they now occupy an assured place in British agriculture and few progressive farmers would attempt to do without them.

Potassic fertilisers have four well marked actions on the crop.

1. They keep the plant growing longer than it otherwise would do; thus they lengthen the growing season. This makes them of great advantage on light, sandy or thin, chalky soils, and especially in dry, warm conditions where the plant tends to end its growth before the growing season is over. Fig. 34 shows the effect of potassic fertilisers on the potato crop at Rothamsted during the very dry season of 1921. The plants receiving no potash died off early, leaving the bare patches seen in the photograph; those that received potash, on the other hand, continued to grow for a longer period. In this respect potassic fertilisers are the opposite of phosphates, which hasten ripening and cause the plant to finish before it otherwise would. For this same reason potassic fertilisers are, except for the crops mentioned below, not usually needed on heavy soils where the plant already tends to grow as long as the farmer wishes it to do and where, indeed, he would often desire it to stop sooner.

Crops that are Helped.

2. They are very useful for starch and sugar-making crops. They are particularly necessary for potatoes, for sugar beet and for mangolds—a crop which yields more sugar per acre than any other usually

Fig. 34.—Effect of potassic fertilisers on potatoes in a dry season at Rothamsted; no dung supplied. The plot to the right had no potash, and shows many bare patches where the plants died before the end of the season. The plot to the left had potash, and the plants lived longer.

grown on the farm. The effect on the mangold crop is shown by the following Rothamsted result:—

Effect of Potash on the Produce of Mangolds at Rothamsted, 1900.

Plot.	Manure.	Leaf per acre.	Roots per acre.	Sugar per acre.
		Tons	Tons.	Tons.
5A	Ammonium Salts and Superphosphate	2.95	12.00	0.797
4A	Ammonium Salts, Superphosphate and Potash	3.25	28.95	2.223

3. They are helpful to clover, peas, lucerne and other leguminous vegetation. This makes them often effective on hay land in keeping up the quality of the herbage, which might otherwise tend to deteriorate with the constant cutting.

4. They give tone and vigour to the crop, enabling it to withstand the attacks of fungus pests. They do not, however, help against insect pests; here nitrogenous fertilisers are better. This action is particularly important to market gardeners and nurserymen, who often incur considerable losses by diseases. An illustration is given in Fig. 35, showing the number of tomato plants affected by a particular disease; the "stripe" is much greater where there is no potassic fertiliser used than where an ample supply is given. The campaign against eel-worm is often facilitated by dressings of potash; thus the tulip root disease, whether of clover or of oats, is often checked by addition of sulphate of potash or kainit. The Irish flax growers have long recognised its value in dealing with wilt disease.

The Common Potassic Fertilisers.

The four common potassic fertilisers are sulphate of potash, muriate of potash, kainit and French kainit. It should, however, be recognised that farmyard manure contains a considerable quantity of potash, usually about 15 lb. to the ton, so that 15 tons of

farmyard manure will supply as much potash as is contained in 4 cwt. sulphate of potash or muriate of potash of the ordinary 50 per cent. grade. Hence the need for potash is reduced where farmyard manure is supplied. This is well shown in one of the Back House field rotation experiments at Cockle Park. The soil is a light, sandy loam of good texture, overlying Millstone Grit sandstone; it is poor in potash, and just the kind of soil one would expect to benefit by potassic fertilisers, and so it does when artificials alone are used. The value of the produce fell off by £3 9s. on the rotation (pre-war value) when potash was left out. But when farmyard manure was used the omission of potash had not nearly so bad an effect.

Plot.	—	Swedes, 1909		Barley, 1910		Hay 1911	Oats, 1912.		Pre-War Value, 4 crops over un-manured.	Pre-war gain less cost of Manure.
		Tons.	cwts.	Grain	Straw		Grain	Straw		
				Bus.	Cwt.		Bus.	Cwt.	£ s. d.	£ s. d.
8	Artificials alone, 6 cwt. for Swedes, also for Hay	16	13½	22½	17½	25¼	48¾	38½	9 9 0	6 2 2
10	Artificials alone, no Potash ..	10	17	19	15¼	20	52½	37½	6 0 3	3 9 0
19	Dung + ½ dressing Artificials for Swedes, also for Hay	24	4½	44	30¾	29¼	56	35¼	17 17 4	11 3 11
22	Ditto but without Potash ..	21	15¼	45¾	33½	30½	52	36¾	17 3 0	10 17 7

The dressings were: Dung, 10 tons per acre; artificials (full dressing), 7 cwt. per acre (1 cwt. sulphate of ammonia, 5 cwt. superphosphate, 1 cwt. muriate of potash).

In the case of mangolds, however, potash is still needed even though farmyard manure is applied. On th Rothamsted mangold field the addition of potash

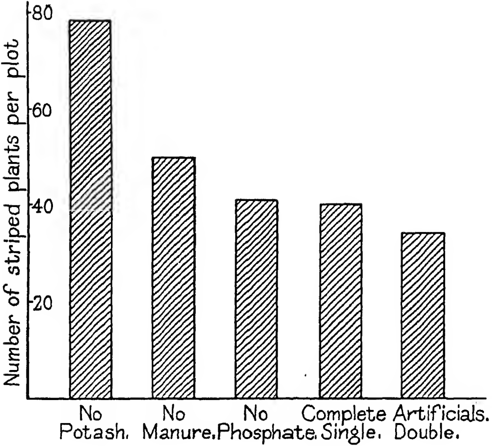


Fig. 35.—Effect of potassic fertilisers on bacterial stripe in tomatoes. A much larger number of plants was effected by disease where potash was left out of the fertiliser.

has much increased the yield, as shown by the following results for 1920:—

MANGOLDS, BARN FIELD.

Roots since 1856; Mangolds since 1876; produce per acre. 1920.

		No other Manure	Nitrate of Soda in addition.	Ammonium Salts in Addition.	Ammonium Salts & Rape Cake in addition.	Rape Cake in addition
Dung	Roots ..	18.99	30.26	21.38	23.89	25.12
	Leaves ..	3.51	4.27	3.95	4.62	5.31
Dung, Superphosphate and Potash	Roots ..	26.84	37.69	33.11	32.67	28.73
	Leaves ..	4.78	6.74	6.69	7.28	5.94

SULPHATE OF POTASH.

For many years sulphate of potash has been the best known of the various potassic fertilisers, and it has repeatedly proved advantageous for potatoes. It increases the yield and also improves the quality; the writer knows of no case where any injury has resulted from its use, so that any farmer uncertain whether it is necessary on his land can always try a little without risk of loss. It is generally used at the rate of about 1-1½ cwt. per acre, and is sold on the basis of 50 per cent. pure potash, chemically denoted by the symbol K_2O.

MURIATE OF POTASH.

This was of little interest before the war, but it has come into prominence since the armistice, as it is produced in large quantities in Alsace, where the mines are being vigorously developed by the French company responsible for the work. Insufficient experience is available in this country to allow of any very definite comparison between the muriate and the sulphate of potash, but a number of experiments are being made under different conditions, and full information will, before long, be available. The present indications are that muriate gives the same yield as sulphate. Farmers wishing to test the material can advantageously do so

on mangolds and hay land. On potatoes it has happened that the quality has suffered, though at present it is impossible to say how far this would be the general rule. $1-1\frac{1}{2}$ cwt. per acre is a suitable dressing.

French Kainit or Sylvinite.

This differs from the German kainit in that it contains no magnesia and no sulphates. Both this and German kainit can safely be used on mangolds and grassland, and for cereals grown on chalk soils. About 3 or even 4 cwt. per acre is a useful application for mangolds, and about 3 cwt. for grass or cereals. As a rule kainit would not be as safe as sulphate of potash for potatoes.

German Kainit.

The German kainit contains about $12\frac{1}{2}$ per cent. of potash, along with salts of soda and magnesium, the effects of which are discussed in the next chapter.

It is sometimes said that kainit increases the amount of moisture in the soil, but this is wholly incorrect.

CHAPTER XV.

SALT, MAGNESIA AND GYPSUM.

These materials are often included in the list of fertilisers, and they have been much used in the past. They do not belong to any of the three great groups of fertilisers—the nitrogenous, phosphatic or potassic—and as a matter of fact none of them is essential as manure. There are, however, cases where they have acted well.

SALT (CHLORIDE OR MURIATE OF SODA).

Years ago salt was much used as a manure on the light sandy and chalky soils of the southern part of England, and there is no doubt it was very effective. Few, if any, precise records seem to have been kept, but experience was very generally in favour of this substance. It acted well on grassland, where it much improved the herbage, and it also improved the yield of cereals. But it gradually went out of use, and now the amount consumed is very small compared with that of other fertilisers. The reason for this is that salt does the same things as potash, but not quite so well. Fifty years ago it would not have been easy to obtain the 100,000 tons of potassium salts which British farmers now purchase every year, and, indeed, most farmers never thought of trying; they used salt, which, though not as good as potash, is an effective substitute on certain crops, and scientific investigation showed that they were right. For salt, although not necessary to plants, can help in regard to the supply of potash, and it does so in two ways.

First of all, salt liberates some of the potash which is locked up in the soil and would not otherwise have become available for the plant. In doing this it naturally impoverishes the soil, but since it enriches the farmer he really cannot grumble. Naturally the process could not be continued indefinitely or both soil

and farmer would become poor; but there is considerable liberation of potash while the process lasts. On the Broadbalk wheat field there are three plots which show this very well. One (No. 11) receives nitrogenous and phosphatic manure only with no potash; the second (No. 12) receives nitrogenous and phosphatic manure and no potash, but instead sulphate of soda, which is similar in action to salt; the third (No. 13) receives nitrogenous, phosphatic and potassic manures. The annual average yields per acre on these plots for the first ten years (1852-1861) were:—

	Grain, bush. per acre	Straw, cwt. per acre
Plot 13.—Complete manure	32.9	34.4
Plot 12.—Soda instead of potash	33.4	34.2
Plot 11.—No potash and no soda	28.4	28.2

Now that is a very satisfactory result, and as sulphate of soda is often cheaper than sulphate of potash, a farmer might think he was doing well for himself. Analysis of the grain and straw showed, however, that the crop receiving complete fertilisers had drawn 532 lb. of pure potash out of the soil during the ten years; the crop receiving sulphate of soda instead of sulphate of potash had drawn out only 78 lb. less, i.e., 454 lb., while that receiving no potash and no soda had taken much less—only 309 lb. It is not surprising therefore to find that a continuation of the soda treatment leads to a market falling off in yield.

In 1920 for instance the results were:—

	Grain, bush. per acre	Straw, cwt. per acre
Complete fertiliser	28.9	39.0
Soda instead of potash	18.4	28.1
No soda, no potash	9.6	21.5

These results show that soda serves quite well as a temporary substitute for potash, but as a permanent fertiliser it is not satisfactory.

There is, however, one crop on which salt is often very effective. Mangolds came originally from the

seaside and they show a marked response to dressings of salt: this has been proved repeatedly in a number of trials in the North, West and Midland areas. At Cockle Park a dressing of 2 cwt. salt increased the yield of mangolds nearly 4 tons per acre on an average of five years when a complete fertiliser was given. At the Harper Adams College 5 cwt. salt applied after sowing added 8 tons per acre to the crop, although farmyard manure (which contains potash) was also given. At the Midland Agricultural College an additional 5 tons of mangolds per acre were obtained from the use of 4 cwt. of salt. In all three cases potash was supplied in one form or another, so that there was no fear of exhausting the stock in the soil. Here then we have the clue to the proper use of salt:

1.—As a dressing for the mangold crop, which, however, should have received farmyard manure and a potassic fertiliser in addition.

2.—In conjunction with potassic fertilisers for grass on light land, or where potash is known to be needed.

Up to 3 or 4 cwt. per acre seems to be a suitable dressing.

How can Salt be Applied?

It can be applied alone, or in conjunction with potash, but in the latter case it is not necessary to mix the salt with the potassic fertilisers, for the mixture is obtainable under the names of kainit and sylvinite, and these are probably the most economical forms of potassic fertilser wherever salt is known to be effective. There is, however, one crop for which salt should not be used, potatoes. Exceptions can be found to every rule in agriculture, but it is pretty safe to say that salt injures the quality of potatoes.

Magnesia: Is it of Use to the Farmer?

Magnesia has been used by farmers in two forms:—

(*a*) as the oxide (pure magnesia) or carbonate, and (*b*) as the sulphate.

The oxide or carbonate was much recommended by one of the older agricultural writers, and I have come across farmers who followed the advice and thought it sound, but I have never found any clear evidence that the material was of value. Dr. Voelcker showed at Woburn that pure magnesia had a remarkable effect on wheat grain, increasing its nitrogen content; possibly it would have some effect on the quality of the potato crop, but there is nothing to show that a farmer would gain anything by using it.

Sulphate of magnesia, on the other hand, has had some useful effects. On the Broadbalk wheat field plot 14 is like plot 12 mentioned above, except that it receives sulphate of magnesia in place of sulphate of soda. The yield for the first ten years was as good as that from the completely fertilised plot, viz., an average of 33.5 bush. of grain and 35 cwt. of straw per acre. But there was the same robbery of the soil potash, and in 1920 the yield was down to 18.2 bush. of grain and 28.8 cwt. of straw per acre. Sulphate of magnesia then, like salt, must, if it is used at all, be used in conjunction with potash. It occurs in German kainit, which also contains salt, though whether there is any advantage in having both salt and sulphate of magnesia is not known with certainty.

On certain sandy soils in the North of England sulphate of magnesia has increased the yield of potatoes even where potash was supplied. The reason for the good effect is not clear.

Gypsum.

Gypsum was formerly much used in this country for leguminous crops and still is applied in special conditions in America, e.g., on alkali land, but otherwise it has fallen out of the list of fertilisers. No recent

experiments have been made with it, but a considerable quantity is always present in superphosphate (a ton of super contains 10 cwts or more of gypsum); and as most farmers buy large quantities of this material, we can still include gypsum among the substances added, although unintentionally, to the soil. It would be interesting and valuable to have tests made, because it might happen that the material had considerable value in certain special conditions.

CHAPTER XVI.

ORGANIC MANURES.

The organic manures include guano, bones, rape cake, shoddy, etc., and they have always had a strong hold on the farmer's fancy. There is something very natural about the idea that a manure coming direct from the animal or the plant has some special value which a mere factory product, such as superphosphate or sulphate of ammonia, cannot possess. The idea is quite reasonable, but no evidence has been obtained in its favour; on the contrary, wherever the trial has been carried out, the well-chosen mixture of ordinary artificials has always proved better than the natural-looking organic manure, in spite of the fact that the latter is usually dearer. The scientific explanation is simple. The plant can take up its food only in the soluble state, and has no use for solid materials, whether organic or not, and as a matter of fact the well-made artificial dissolves more easily than the organic manure. It is sometimes considered useful to have a slow acting manure, but I can never see the advantage of this. Manure is put into the ground with the idea of making a profit, and surely the quicker the profit is made the better. The more complete and rapid the utilisation of the manure, the larger and quicker must be the return to the farmer.

It is also claimed that the organic matter must be advantageous to the soil, since it is known to improve the tilth, the water-holding capacity, and other physical properties, all of which are of great advantage to the farmer. This claim cannot lightly be dismissed, but on the other hand it is very easy to exaggerate the quantity of organic matter added in an organic manure; only rarely would one apply more than 5 cwt. per acre of rape cake or guano, and this would not all be organic; further, the addition is not made every

year. An ordinary soil contains some 50 tons of organic matter per acre in the top 9 inches, and it is difficult to see how an occasional addition of 4 or 5 cwt. can affect this very seriously. In the case of farmyard manure the position is different, as some 10 tons per acre are used, of which about a quarter is organic. There is, however, one great advantage about "organic" manures: they are very nearly foolproof, and a farmer who can afford to do without a good knowledge of artificial fertilisers can safely use them.

Guano.

This fertiliser came into England about 1840 and achieved a high reputation almost at once. It had few competitors; superphosphate had not been invented, and neither nitrate of soda nor sulphate of ammonia were commonly regarded as valuable fertilisers. It has largely gone out of use for ordinary farming, but it still retains a permanent place in horticulture for raising certain plants. At Rothamsted it gives good crop increases in the first year, but it is inferior to artificials, and there is no sign of any particular residual effect; nothing can be detected in the second and third years after application. A few trials have been made elsewhere with the same result. In the very excellent field experiments of the Norfolk Chamber of Agriculture, made in the late 'eighties, and which are a model of carefulness and accuracy, a high-class guano was found inferior to nitrate of soda or sulphate of ammonia on swedes and barley, and, of course, it was more expensive. A similar result was obtained at Cirencester on the hay crop.

Rape Cake.

This is one of the oldest of manures, having been in regular use for at least 200 years. It has been much tested at Rothamsted with fairly satisfactory results,

though it is inferior to the properly made mixture of artificials and also dearer. On barley, for instance, the proper mixture of artificials gives nearly 43 bushels of grain and 27 cwt. of straw, while 9 cwt. per acre of rape cake give only 38¼ bushels of grain and 22 cwt. of straw. A man, therefore, using the proper mixture of artificials will gain something more than 10 per cent. on his crop as compared with another who used rape cake, and in addition would spend less. But where a faulty mixture of artificials is used the result is less satisfactory; where phosphates are omitted, the yield is down to 30 bushels instead of 43, and it is now much less than where rape cake is given. Thus, while the right mixture is profitable and superior to rape cake, the wrong mixture is unprofitable and is inferior to rape cake—an illustration of the rule given above, that organic manures are more foolproof than artificials.

Shoddy.

This is quite a useful material, the value of which is already fully recognised by fruit and hop growers in Kent and by other growers near the mills. The actual fertilising action is due to the wood, which supplies nitrogen and organic matter, and although the latter is not great in amount, it accumulates when the shoddy is applied regularly in heavy dressings, as in hop gardens. Usually the nitrogen is considerably cheaper per unit than that in sulphate of ammonia or nitrate of soda. At Rothamsted shoddy is found to act quite well for all crops; it is not as effective as guano, but it is cheaper and has some residual value. It should be purchased on its nitrogen content and should compare very favourably in price per unit with sulphate of ammonia. Thus a shoddy containing 10 per cent. of nitrogen should be distinctly less than half the price of sulphate of ammonia, which contains 20 per cent. nitrogen; the prices of samples of other composition should vary accordingly. 5-10 cwt. per acre can be used.

Bones.

Bones are so well known to farmers that it might seem unnecessary to speak about them. Actually, however, there is some misapprehension with regard to them. They have to compete with the phosphatic fertilisers, and, in the case of bone meal, with organic nitrogenous compounds. As usual with organic manures, they are very safe in practice, and can be entrusted to anyone without much knowledge of artificials; but their value is sometimes overrated, and we farmers sometimes pay more for a bone fertiliser than is really justified.

So far as the phosphatic part is concerned, bones are not usually as good as basic slag on grass land, nor as quick in action as superphosphate on arable land. The nitrogen has considerably less value than that in nitrate of soda or sulphate of ammonia. The comparison of bones with other fertilisers must be made in recognition of these facts. If bones are cheaper per unit of nitrogen and of phosphate it may be worth the farmer's while to purchase them; if they are no cheaper it is unlikely to be worth his while to do so. Prolonged tests have been made with bones at Rothamsted and elsewhere, but only rarely have they proved as good as the ordinary artificials, and usually they have come out inferior. There is no justification, therefore, for paying as high a price for them. Where there is any doubt inquiry should be made of the Agricultural Organiser for the County, who can obtain the desired information.

Soot.

Soot is one of the most useful of the waste product manures, and it is applied with great advantage as a spring dressing to winter cereals. It not only supplies the nitrogen, which is so much needed in the early part of the year, but it keeps off slugs, insects, etc., and it helps to warm the ground. But not all kinds

of soot are equally useful; by far the best is the ordinary household soot. Usually a bushel of this material contains about 1 lb. of nitrogen, 22 bushels being about the equivalent of 1 cwt. sulphate of ammonia. Some samples are richer, however. Factory soot is nothing like as good; the factory fire is a more efficient affair than the ordinary domestic fire, and the soot is correspondingly poorer; it should be bought only on analysis, as some samples are useful and others are not. Destructor soot or dust sometimes offered to farmers is, in my experience, worthless, even as a gift.

Sewage: Will It Help the Farmer?

One of the most interesting problems before the agricultural expert is to try and find some way of utilising the sewage of the United Kingdom for purposes of manure. The problem has been before us for many years; a large number of attempts have been made at different times, but farmers still obtain very little good out of sewage. And yet the value of the material over the whole country is considerable. The amount of nitrogen consumed by the inhabitants of the United Kingdom in a year is 230,000 tons, equivalent to more than 1,000,000 tons of sulphate of ammonia, and to 1,250,000 tons of nitrate of soda: this is three or four times as much as the British farmer is likely to use for some time. But a good deal of this nitrogen never appears in the sewage at all, and the fraction that does get there is largely lost in the purification process.

If all the nitrogen could be recovered it would amount to 11 lb. per head per annum; the phosphate and potash are smaller in quantity. The nitrogen is mainly in a very available form. At present prices the manurial value of the whole of the excretions of an adult is about one halfpenny per day, and the figure enables us to understand why the many efforts at

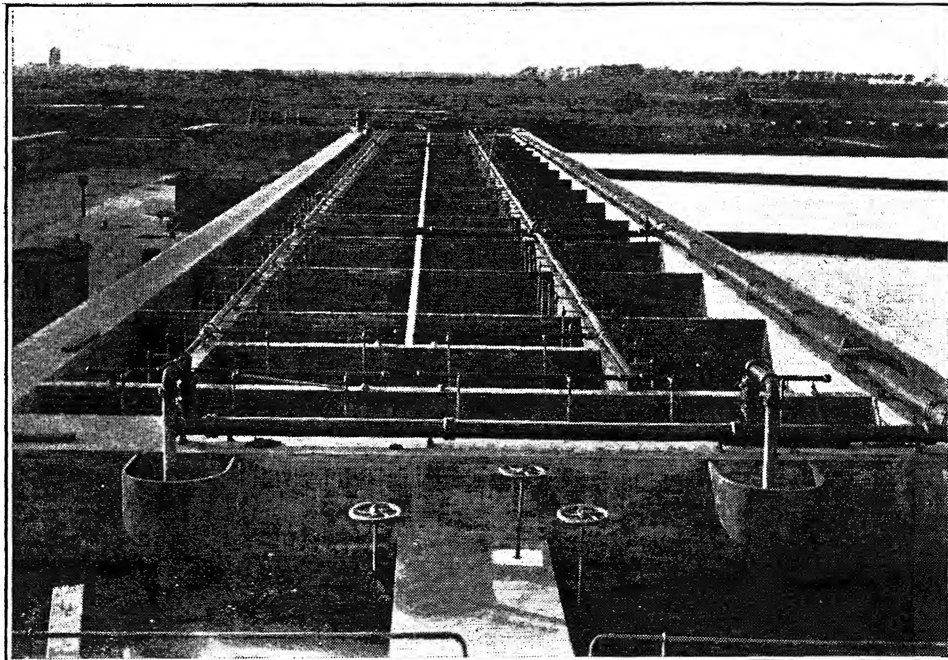


Fig. 36.—Modern Sewage Plant, giving a sewage sludge very useful to farmers.

utilising human excretions have failed in this country. It is done in China, and, agricultural travellers tell us, with great success; but labour is vastly cheaper there than here.

But although the manurial value of an individual is small, that of a city is great: the excretions of the population of London are probably worth some £3,000,000 per annum as fertiliser, and if only a portion of this could be saved it would greatly help the city to pay the expenses of cleansing, etc. This, indeed, is the soundest way of approaching the subject.

Methods.

Several methods have been used, with varying success. The oldest consists in running the sewage on to land and then growing crops; it was much practised some 40 or 50 years ago, and was successful so long as sufficient land was available and sufficient attention paid to the drainage. Good examples were to be seen at Birmingham, at Beddington, near Croydon, and under the farms managed by Col. Alfred Jones. Rye grass and cabbage made good growth, mangolds also were usually satisfactory. When, however, the cities grew and the population began to take more baths and generally use more water, it became increasingly difficult to find sufficient land to deal with all the sewage. The method therefore went out of use, being displaced by the more compact septic tanks. This gave a sludge from which great things were expected, so that farmers often paid more for it than it was worth. The writer has come across cases where farmers paid 55s. per ton for material that could hardly have been worth more than 25s. Careful experiments in different parts of the country showed that these sludges had some value, especially in wet districts, but not as much as could reasonably have been expected from a sewage product. Analysis showed that they contained only

1 per cent. of nitrogen, and that was in a rather unavailable form.

A later process in which air was admitted instead of being excluded gave a better sludge, containing 2 per cent. or more of nitrogen, and capable of producing better effects, since it was more available. A more recent process, known as the activated sludge process, comes out still better, giving a sludge containing as much as 6 per cent. or more of nitrogen, and over 4 per cent. phosphoric acid, equivalent to 10 per cent. of the standard tri-calcic phosphate. Experiments show that this material is quite promising; a cheap method of drying seems alone to be needed to give a highly useful fertiliser.

Value of a Sludge.

It is not easy for a farmer to form an opinion as to the value of a sludge. A disagreeable look or smell implies nothing: a sludge may have a very unpleasant smell and still have little value as a fertiliser. The percentage of nitrogen is a tolerably safe guide; a high percentage (5 per cent. or 6 per cent.) indicates a good class material which can be bought at a good price; a smaller percentage (such as 2½ per cent. or 3 per cent., present in some of the northern sludges) is also quite good, but a low percentage (such as 1 per cent. to 1½ per cent.) suggests an unavailable condition, and is a warning that the material may not be worth much. Some sludges, however, have a value in that they contain much lime and can be used wherever this constituent is necessary. On the other hand, it is necessary to caution farmers against the suggestion sometimes made that sludge contains bacteria which are helpful in increasing the fertility of the soil. There is no ground whatsoever for this assumption, and no reason to suppose that any of the bacteria thus introduced are of the least value to the farmer. Perhaps the best

final advice to give in regard to sludges is to buy them only on an analysis, and to make sure that the money is being laid out to the best advantage in using them. So long as no fanciful price is paid a farmer is not likely to go wrong if he gets good advice at the outset.

Occasionally it is possible for a farmer to contract to take the village sewage for broad irrigation on his land. In some conditions this is quite useful, particularly on grass land where the soil or the slope is such that good drainage is possible. It is, however, necessary to attend most closely to drainage and to arrange for frequent redistribution of the sewage channels, so as to avoid excessive rankness and coarseness of the herbage.

Corporation Manure.

In some towns the Corporation makes up a fertiliser from market wastes, slaughterhouse residues, sewage sludge, and other materials. These are distinctly useful. They should, however, be purchased on analysis, and after being advised as to the real value on the particular farm.

Ashpit Refuse.

There is a growing tendency on the part of towns to screen their ashpit refuse and send out the resulting material into the country as manure. Other city wastes, street sweepings, slaughterhouse refuse, stable manure, etc., are often, though not always, incorporated with it. The material has long had some degree of popularity among farmers situated near towns, especially those on heavy soils. Analysis does not help much in assessing its manurial value; as a rule the figures come out somewhat as follows:—

Organic matter	25 — 40 %
Nitrogen	0.4 — 0.6 %
Phosphoric acid (P_2O_5)	0.3 — 0.5 %
Equivalent to tri-calcic phosphate ($Ca_3(PO_4)_2$)	0.7 — 1.1 %
Potash (K_2O)	0.3 — 0.5 %

These figures are not unlike those for farmyard manure, and it is sometimes suggested that the material itself must therefore be of equal value to the farmer. But this is fallacious: it differs so much from farmyard manure that no fair comparison can be made. Screened ashpit refuse is always worth trying by those heavy-land farmers who have not previously used it, especially if it can be had for 3/- or 4/- per ton on the farm, but the test should be on a small scale first. It is not likely to be worth more than about 5/- or 6/- per ton on the farm.

Destructor Refuse.

This is rarely of value to the farmer, and should not be used except on expert advice.

CHAPTER XVII.

LIME, LIMESTONE AND CHALK.

These are among the oldest manures in use; they are well known, and their value is universally admitted, yet they are not now used as extensively as was once the case, and although everyone deplores this fact, it remains unaltered. Three reasons may be given for this falling off :—(A) The cost is high; (B) basic slag produces some of the effects of lime and thus to some extent does away with the necessity for using it; (C) lime and limestone have not invariably succeeded, and it has happened that a considerable sum of money has been spent with rather disappointing results.

A good deal of work has been done by agricultural experimenters, and the reasons for some of the failures are now known. It has been found that the action of lime is very complex; it does several different things in the soil, some of which are wanted and some are not, and only when a farmer understands exactly what it can do will he be in a position to use it to the greatest advantage.

ARABLE LAND.

On heavy arable land lime is nearly always an advantage. If used as ground lime or quick-lime, it lightens the soil and makes for easy working; it greatly improves the chances of a stand of clover, and it helps the turnip crop considerably. Only one crop does not need it—potatoes—and, where these are grown on heavy soil, lime should not be applied till they are safely out of the ground. In addition to all these effects, lime keeps down a certain number of pests, and so gives the crop a greater chance of growth. Ground lime has, however, the disadvantage that it is not particularly easy to store, as it is liable to absorb water, swell, and to burst its bags; also it is not particularly easy to apply to the land, as it tends to give trouble

to the men, and so to the farmer. Hydrate of lime has much the same effect as ground lime, and is easier to store and to apply. Whether, however, it is quite as potent against pests is not clear, but in all other ways it is probably fully equal to lime: not of course ton for ton, but when compared on the proper basis (see p. 117). Ground limestone improves the texture of the soil, it increases the chance of a good stand of clover, and it keeps down finger and toe in turnips, swedes, cabbages, and other crops liable to the disease, but it is not particularly effective against other pests. The choice between ground limestone and lime must therefore depend upon what exactly the farmer wishes to have done; if he wants anything that limestone can do, he can buy it so long as the price is sufficently attractive. On the other hand, if he is trying to keep down small slugs or other animals that are injuring his crop, he must use the burnt lime. Chalk is very useful in those districts where it can be obtained cheaply. Over most of the Home Counties there are chalk pits from which farmers can draw supplies, and many farms lie so near to the chalk that it is necessary to go down only a short distance to find it. The old practice was to sink wells in autumn in different parts of the field (one to about 3 or 4 acres), to draw the chalk and spread it, giving the substantial dressing of 40 to 80 tons per acre; the lumps were left on the surface to be broken by the winter frosts, then ploughed in, and turned up again during the next winter to be further shattered. The method has been tested at Rothamsted, and is very effective; dressings of 20 to 50 loads per acre lightened the heavy soil so much that in walking over the ground during wet weather one could pick out the chalked areas by their dry appearance and their open texture, while the unchalked land had a wet, glazed appearance. The crops did not show as large an improvement as might have been expected;

Fig. 37.– Chalking in Hertfordshire—a highly useful practice.

clover and barley benefited, but potatoes, wheat, mangolds, etc., did not.

The ploughman always declared, however, that he could work more easily on the chalked than on the unchalked land. No measure of this difference could be obtained with horse implements, but it can be done with a tractor. Dynamometer measurements were taken when cross ploughing land previously ploughed in autumn; these showed that the effect of chalking is to increase the speed of ploughing and to reduce the draw bar pull on the three-furrow plough by no less than 200 lb.

	Plough A		Plough B	
	No Chalk	Chalked	No Chalk	Chalked
Miles per hour	2.18	2.23	1.98	2.21
Draught per plough lb.	513	453	537	475
Per square inch in furrow section, lb..	7.25	6.46	7.67	6.8
Draw bar pull, lb.	1538	1358	1610	1425

Now this saving in pull means a corresponding saving in fuel consumption and in wear and tear, while the saving in time resulting from the increased speed means an additional economy. When all the cultivations of the year are added up it does not take long to repay the cost of the chalking. There is little doubt that lime, hydrate of lime and ground limestone would have had the same effect, though we are not yet able to say what is the smallest dressing that will act. There is no point in putting on more than is necessary.

Light soils also benefit by lime or limestone, but in this case the action is to help the turnip, swede or rape crops, the clovers and other crops, such as vetches, grown as sheep feed. Whenever clover is failing in patches an examination should always be made for lime; in the writer's experience, lack of lime is a common reason for failure. In really bad cases mangolds fail, refusing to grow, producing only small

spindly roots and going yellow in the leaf. Here again the failure is in patches. The lime, however, should not be applied till after potatoes are removed, or there is a liability to scab. A case was investigated at Rothamsted where soil, otherwise suited for potatoes, was rendered useless for the crop because of the scab, while in a neighbouring field there was much less tendency. The "scabby" soil contained a distinct amount of carbonate of lime (0.5 per cent.), while the safe and healthy soil did not, the amount being too small to be easily estimated.

When we come to grassland, however, it is more difficult to give any general advice. Land laid in for hay can often receive lime or limestone with advantage; this is a recognised custom in the north, and it is practised in many other parts of the country with advantage. At Rothamsted a single application of 28 cwt. per acre of lime has raised the crop in some cases by as much as 10 cwt. of hay per acre over the average of the next four years, and at the same time has improved its quality. But this does not always happen, and the effect depends on the season, and on the manuring, being especially marked when sulphate of ammonia, farmyard manure, or liquid manure is used to increase the bulk of the herbage. Grazing land presents a more uncertain case. Where slag has been liberally used, it is improbable that lime will be needed; though cases arise in Yorkshire where the land is so sour that slag will not act till lime is added. Where the system is to feed cake on the land, lime may prove of great advantage. No general rule can be given; the farmer must make a trial and see whether the result justifies the expenditure.

In cases where lime is costly the farmer may try a succession of crops which can tolerate sourness. Rhubarb is the most tolerant of all crops: potatoes and oats can get along fairly well without lime, and of

the various clovers alsike is more likely to succeed than others. On the other hand red and white clover will not flourish in acid soils.

HOW TO PURCHASE LIME AND LIMESTONE.

We must distinguish carefully between three forms: the pure, or quicklime; the hydrated lime or hydrate of lime; and the carbonate of lime, also offered as ground limestone. All these finally turn into carbonate when put into the soil, but, as pointed out above, the quicklime kills certain insects. So far as action in the soil is concerned, 100 parts of carbonate of lime has the same value as 74 parts of the hydrate, or 56 parts of the pure burnt lime. Thus, if a farmer is offered good quicklime at £2 per ton and ground limestone of equal purity at 25s. per ton, he is getting more material for his money in the quicklime than in the limestone. The following table shows the actual values for ground limestone and hydrated lime when quicklime is obtainable at the prices quoted:

Quotation for Quicklime or good burnt lime of the same puity, per ton		Equal value for Hydrate of Lime of the same purity, per ton		Equal value for Carbonate of Lime, (ground limestone) per ton	
s.	d.	s.	d.	s.	d.
20	0	15	1	11	2
30	0	22	7	16	9
40	0	30	0	22	4
50	0	37	8	27	11
60	0	45	3	33	6

Allowances must, of course, be made for the fact that ground limestone and hydrated lime are more readily stored and more easily applied to the soil than quicklime, as they cause less trouble to the men. If any large expenditure is being incurred, an analysis should be obtained giving the degree of purity. Wherever waste limes or lime muds, etc., are purchased, an analysis should always be made.

1 to 2 tons per acre of quicklime, or double these quantities of ground limestone, can be used.

CHAPTER XVIII.

CONCLUSION.

Signs for Special Requirements.

In the preceding chapters we have discussed the effects of fertilisers on crops and on soils, and the way these effects are alterd by seasons. We must now point out that every farm must be treated like an individual, and no farmer must expect any general recipes to answer all over his land. It is quite possible that a certain potato manure may be the best possible on one farm, but by no means the best on the next farm. There is no such thing as a universal manure suited to every soil and season or to every farm in a district. The ideal thing would be for every farmer to have his own special manurial recipes, and some of the best men have already done this; those who have not can learn a good deal as to their special requirements by studying the appearance of the crops. The following are useful signs:—

Lime is lacking (1) if clover in seeds leys tends to fail or to become patchy; (2) swedes and turnips become liable to finger and toe; (3) mayweed spreads among the corn; (4) dark green patches occur in the meadows and clover begins to fail.

Phosphates are needed (1) if corn crops do not ripen evenly or if they ripen late; (2) for all root crops or fodder crops to be fed to animals; (3) for potatoes.

Potassic fertilisers are needed (1) if the corn crops finish growth too soon, if the yield of grain is disappointing in view of the nitrogen and phosphates given, or if the heads do not fill out well; (2) always for mangolds and potatoes and often for leguminous crops; (3) for many crops on light, chalky or sandy soils.

Nitrogenous fertilisers are needed (1) always for mangolds, potatoes and hay crops; (2) usually as spring

dressing for winter corn, particularly after a wet winter; and (3) for second corn crops.

Reference should be made to the preceding chapters to determine just which of the various fertilisers should be used, at what time, and in what quantity.

Field trials are highly desirable in order to ascertain the best basis for a fertiliser scheme. They should, if possible, be arranged by the county organiser or by a Farmers' Club, as in that way a uniform scheme can be arranged which may benefit a number of farmers.

How to Compare the Prices of Manures.

Manures are always sold on the basis of their chemical analysis, and this should always be carefully examined. Condition is of great importance and must be judged on appearance. But the real material composition can be determined only by the chemist, and the farmer who thinks he can judge a fertiliser simply by inspection is not only deceiving himself, but encouraging others to deceive him. The best method of comparison is the unit system, and a good way of working out the value on this basis is as follows: Divide the prices of nitrate of soda and sulphate of ammonia by their percentages of nitrogen; divide the prices of superphosphate and basic slag by their percentages of phosphate; and the prices of sulphate of potash and muriate of potash by their percentages of potash. This gives the price of each per cent. of the fertilising material in a ton. This is called a unit. Some recent results are:—

Name of Fertiliser	Price per ton	Percentage of	Unit price of
	£ s. d.	Nitrogen	Nitrogen s. d.
Nitrate of soda 95 %	13 2 0	15.6	16 11
Sulphate of ammonia 25¼ %	16 0 0	20.8	15 5
		Phosphate	Phosphate
Superphosphate	3 12 0	30.0	2 5
Basic slag	2 12 0	20.0	2 6

From these it appears that for unit of nitrogen supplied, sulphate of ammonia was cheaper than nitrate of soda, and superphosphate slightly cheaper than basic slag. In cases where sulphate of ammonia is as effective as nitrate of soda, it would therefore be preferred, as would superphosphate to basic slag when it is equally useful to the farmer. In trying to find whether the price of a compound fertiliser is fair, it is reasonable to assume that the fertiliser will not be better than a mixture of sulphate of ammonia, superphosphate and sulphate of potash, and therefore should cost no more. The method, therefore, would be to see what it would cost to make up a mixture of the same composition. Thus, to find the fair price of a compound fertiliser containing 3 per cent. nitrogen and 20 per cent. phosphate we should proceed :—

	£	s.	d.
3 per cent. Nitrogen=3 units per ton	2	6	3
20 per cent. Phosphates=20 units per ton	2	8	4
Basal price	£4	14	7

On the top of this basal price, however, it is only fair to add certain other charges, since a merchant mixing these manures to order and making a sound job of it would make a charge. Something will also be claimed by the dealer for his skill in devising the formula. It is usual to add about 10 per cent. for these services, and on this basis the fair price, assuming high-class materials, would be about £5 4s. But this would only be for reasonably large quantities and for cash; if only small amounts were ordered and credit were desired, something additional becomes necessary.

THE FARMERS' MANURIAL CALENDAR.

Autumn.—Try and draw up a good scheme for manuring the whole farm. Be fairly liberal to costly crops like potatoes, and to heavy yielders like mangolds; do not overdo the manuring for swedes unless

you can expect 20-25 tons or more per acre. Do not neglect the grassland, and do not forget a top dressing for winter corn. Order the manures early so as to be sure of having them in time, and give them dry storage.

Early Winter.—Apply basic slag to permanent grassland and, if necessary, to temporary grass or seeds leys. Apply farmyard manure to the root and potato land, excepting only where the rainfall is high. Apply lime or limestone where necessary.

Spring.—Give top dressing of nitrate of soda or sulphate of ammonia to winter corn. If you fear the corn may be laid, add 1 cwt. superphosphate. Apply the manures for the root and potato crops. Use sulphate of ammonia for the potatoes and for barley. Give manurial dressings to the hay crop: nitrate of soda or sulphate of ammonia, basic slag, or kainit, as may be necessary.

Early Summer.—When mangolds are well up, give a top dressing of nitrate of soda and, if necessary, of salt also.

Finally, remember the advice of Arthur Young, given more than 120 years ago, but perfectly true yet: "If our young farmer has any relation, friend, or confidential bailiff, that he can trust his farm to for ten days or a fortnight, let him now take his nag for a summer tour, to view some farms in well-cultivated counties, and to introduce himself to the conversation of his intelligent brethren, from whom he will be sure to learn something useful." Which, in modern language, is, "Get into your car or on to your motor-cycle or push-bike and have a tour in a good farming district, visiting any experimental stations you can." I should like to add that, if the way lies anywhere near to Rothamsted, farmers are always welcomed there, and are shown round the plots without any formality or previous notification.